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SATURN S-IVB-508 STAGE ACCEPTANCE FIRING REPORT

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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PREPARED FOR:
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
UNDER NASA CONTRACT NAS7-101

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ABSTRACT

This report presents an evaluation of the Saturn S-IVB-508 stage acceptance firing that was conducted at the Sacramento Test Center on 20 February 1969. Included in this report are stage and ground support equipment deviations associated with the acceptance firing configuration.

The acceptance firing test program was conducted under National Aeronautics and Space Administration Contract NAS7-101, and established the acceptance criteria for buyoff of the stage.

DESCRIPTORS

Saturn S-IVB-508 Stage

Saturn S-IVB-508 Stage Test Evaluation

J-2 Engine

Complex Beta

Countdown Operations

Saturn S-IVB-508 Stage Acceptance Firing

Saturn S-IVB-508 Stage Test Configuration

Sacramento Test Center

Sequence of Events

O_2-H_2 Burner

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PREFACE

This report documents the evaluation of the Saturn S-IVB-508 stage acceptance firing as performed by MDAC-WD personnel at the Sacramento Test Center.

The report was prepared under National Aeronautics and Space Administration Contract NAS7-101 and is issued in accordance with line item 129 of the MSFC Data Requirements List 021, dated 15 September 1966.

This report evaluates stage test objectives, instrumentation, and configuration deviations of the stage, test facility, and ground support equipment.

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SECTION 1

INTRODUCTION

1. INTRODUCTION

1.1 General

This report was prepared at the McDonnell Douglas Astronautics Company - Western Division (MDAC-WD) Huntington Beach (HB), by the Saturn S-IVB Test Planning and Evaluation (TP&E) Committee for the National Aeronautics and Space Administration under Contract NAS7-101.

Activities connected with the Saturn S-IVB-508 stage included a prefiring checkout and the acceptance firing. Checkout started at the subsystem level and progressed to completion with the integrated systems test and the simulated acceptance firing. The information contained in the following sections documents and evaluates all events and test results of the acceptance firing which was completed on 20 February 1969. The tests were performed at Complex Beta, Test Stand III, Sacramento Test Center (STC).

1.2 Background

The S-IVB-508 stage was assembled at MDAC-WD/HB. A checkout was performed in the vertical checkout laboratory (VCL) prior to shipping the stage to STC. The stage was delivered to STC on 31 December 1968 and installed on Test Stand III on 3 January 1969. The stage was ready for acceptance firing on 17 February 1969.

The APS modules were shipped to Santa Monica checkout laboratory for production acceptance tests. The modules were then shipped to STC for stage interface checks. No confidence firings of these modules were scheduled.

Table 1-1 lists the milestones of the Saturn S-IVB-508 stage events and dates of completion.

1.3 Objectives

All test objectives outlined in drawing No. 1B71775D, Test Plan Acceptance Firing, S-IVB/SV-STC, dated 27 January 1969 were successfully completed.

Stage acceptance objectives which provide maximum system performance evaluation were as follows:

a. Countdown control and operational capability verification

b. J-2 engine system performance verification

c. Oxidizer system performance verification

d. Fuel system performance verification

e. Pneumatic control system performance verification

f. Propellant utilization system performance verification

g. Stage data acquisition system performance verification

h. Stage electrical control and power system performance verification

i. Hydraulic system performance and J-2 engine gimbal control performance verification

j. Structural integrity verification

k. Auxiliary propulsion system stage interface compatibility verification

l. Ambient repressurization system performance verification

m. O_2-H_2 burner performance verification.

TABLE 1-1
MILESTONES, SATURN S-IVB-508 STAGE

Event	Completion Date
Tank assembly	8 August 1967
Proof test leak and dye	23 August 1967
Insulation and bonding	26 Sept. 1967
Stage checkout and join J-2 engine	2 Feb. 1968
Systems checkout	20 May 1968
Ship to STC	30 Dec. 1968
Stage installed on test stand	3 Jan. 1969
Ready for acceptance firing	17 Feb. 1969
Acceptance firing	20 Feb. 1969
Abbreviated postfire checkout on stand	25 March 1969

SECTION 2

SUMMARY

2. SUMMARY

The S-IVB-508 stage was acceptance fired on 20 February 1969 at Complex Beta, Test Stand III, Sacramento Test Center. The countdown was designated as CD 614116. The mainstage firing duration was 456.3 sec; engine cutoff was initiated by the LH2 depletion sensors.

2.1 Countdown Operations

Countdown 614116 was initiated on 18 February 1969 and proceeded to a successful acceptance firing on 20 February 1969. The acceptance firing was preceded by a simulated orbital coast, cold helium leak check, O_2-H_2 burner firing, and an ambient repressurization test.

2.2 J-2 Engine System

The S-IVB-508 stage utilized an uprated (230,000 lbf thrust) J-2 engine, (S/N J-2122). All systems operated satisfactorily and the performance predictions were well within the allowable deviations. All hardware functioned normally.

2.3 Oxidizer System

The oxidizer system functioned adequately supplying LOX to the engine pump inlet within the specified limits. The net positive suction pressure (NPSP) available to the LOX pump inlet exceeded the engine manufacturer's minimum requirement at all times.

2.4 Fuel System

The fuel system performed as designed and supplied LH2 to the engine within the limits defined in the engine specification. The LH2 tank pressurization system adequately controlled LH2 tank ullage pressure throughout the firing and during the repressurization periods.

2.5 Pneumatic Control and Purge System

The pneumatic control and purge system performed adequately during the acceptance firing. All components functioned normally.

2.6 Oxygen-Hydrogen Burner System

The O_2-H_2 burner performed satisfactorily during the 460 sec of operation. The LOX tank was repressurized 178 sec after burner start, and the LH2 tank repressurization was terminated approximately 3.9 sec later.

2.7 Propellant Utilization System

The PU system generally performed satisfactorily. However, a minor anomaly occurred when the closed-loop valve response exhibited anomalous activity because of a sticky PU valve. The valve was replaced.

2.8 Data Acquisition System

The data acquisition system performed satisfactorily throughout the O_2-H_2 burner and mainstage firing. Two hundred and twenty-nine measurements were active of which three failed resulting in a measurement efficiency of 98.7 percent.

2.9 Electrical Power and Control Systems

The electrical power and control systems performed satisfactorily throughout the acceptance firing. All firing objectives were satisfied and all systems variables operated within design limits.

2.10 Hydraulic System

The hydraulic system operated properly supplying pressurized fluid to the servo-actuators. All specified test objectives were achieved with one exception. The auxiliary hydraulic pump canister pressure regulator allowed the canister pressure to exceed the limits of 15 ± 5 psig. This is being corrected.

2.11 Flight Control System

The dynamic response of the hydraulic servo-thrust vector control system was measured while the J-2 engine was gimbaled during the acceptance firing. The performance of the pitch and yaw hydraulic servo control systems was satisfactory.

2.12 Structural Systems

Structural integrity of the stage was maintained for the vibration, temperature, and thrust load conditions of the acceptance firing with the exception of cracking and peeling of Korotherm ablative coating on certain areas of the forward skirt. The damaged coating is to be repaired under direction of Materials & Methods/Research and Engineering.

2.13 Thermoconditioning and Purge System

The thermoconditioning and purge system functioned properly supplying purge and environmental conditioning to the stage within design limits.

2.14 Effectiveness Engineering

All malfunctions of Flight Critical Items were investigated and documented as follows:

Total number of malfunctions	5
Number of items reworked in place and accepted by engineering	1
Number of items replaced	3
Number of items determined to be acceptable by engineering	1

SECTION 3

TEST CONFIGURATION

3. TEST CONFIGURATION

This section describes the stage and ground support equipment (GSE) deviations and modifications from the flight configuration affecting the acceptance firing. Additional details of specific system modifications are discussed in appropriate sections of this report. Details of the S-IVB-508 stage configurations are presented in drawing No. 1B66684, S-IVB/V Stage End-Item Test Plan.

Figure 3-1 is a schematic of the S-IVB-508 stage propulsion system and shows the telemetry instrumentation transducer locations from which the test data were obtained. The propulsion system orifice characteristics and pressure switch settings are presented in tables 3-1 and 3-2. J-2 engine S/N J-2122 was installed.

The propulsion GSE consisted of pneumatic consoles "A" and "B," two propellant fill and replenishing control sleds, a vacuum system console, and a gas heat exchanger.

3.1 Configuration Deviations

Configuration deviations required for the acceptance firing are discussed in drawing 1B71775D, Test Plan, Acceptance Firing, S-IVB/SV-STC. Significant configuration changes to the stage and GSE for the acceptance firing are discussed in the following paragraphs.

3.1.1 Propulsion System

a. Stage propellant vent and bleed systems were connected to the facility vent system. The nozzles were removed from the LH2 tank continuous vent system and the LOX and LH2 nonpropulsive vent systems.

b. The stage portions of the propellant and pneumatic quick-disconnects were replaced with hardlines.

c. A converging water-cooled diffuser was installed in the engine thrust chamber exit to reduce the possibility of sideloads induced by jet stream separation.

d. A GN2 ejector system was used to provide low pressure environment at the O_2-H_2 burner nozzle exit.

e. A heated GN2 purge was used for the LOX dome to prevent injector icing during the simulated orbital coast.

3.1.2 Propellant Utilization System

The propellant loading fast-fill sensors installed on the instrumentation probes were used in the indicating mode only.

3.1.3 Electrical Power System

a. Model DSV-4B-170 battery simulators were used to supply stage internal power.

b. Model DSV-4B-727 primary battery simulators were used in place of primary flight batteries.

3.1.4 Electrical Control System

a. The instrument unit and S-IVB/V stage electrical interfaces were simulated by GSE.

b. Two Model DSV-4B-188B APS simulators were used to provide APS module electrical loads to the stage control signals.

c. The electrical umbilicals remained connected throughout the acceptance firing.

3.1.5 Data Acquisition System

a. The MSFC Basic Static Firing Measurement Program hardwire transducers were installed.

b. All instrumentation parameters without transducers, and those disconnected for hardwire usage, were left as open channels.

3.1.6 Forward Skirt Environmental Control System

Coolant for the forward skirt thermoconditioning system was supplied by Model DSV-4B-359 Servicer.

3.1.7 Secure Range Safety Command System

a. The Engine Cutoff Command output from Range Safety Systems 1 and 2 was disconnected and stowed.

b. Pulse sensors were attached to the output of the exploding bridgewire (EBW) firing units.

3.1.8 Structural Systems

a. The main and auxiliary tunnel covers were not installed.

b. The stage was mounted on the Model DSV-4B-540 Dummy Interstage.

3.1.9 GSE and Facilities

a. Resistance wire fire detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

b. GH2 leak detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

c. Blast detectors were installed in the test area for monitoring ranges of 0 to 25 psi overpressure.

d. Model 742 static firing hazardous gas shield, thrust cone water spray Firex, cryogenic spill pan, forward skirt support ring, and vent port covers were installed.

e. Model 601 flame resistant protective firing cover was installed to enclose the forward skirt area.

f. An auxiliary propellant tank pressurization system was installed using a GSE ambient helium source.

g. Model DSV-4B-618 Engine Unlatch Restrainer Links were installed to restrain the J-2 engine during start transient sideloads.

TABLE 3-1

S-IVB-508 STAGE AND GSE ACCEPTANCE FIRING ORIFICES

DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in^2)
Stage			
Continuous vent bypass valve actuation control module inlet	0.017 in. dia	--	N/A
Continuous vent bypass valve bellows purge	300 scim with 3,200 psid	--	Sintered
Continuous vent bypass valve switch cavity purge	15 scim with 3,200 psid	--	Sintered
Continuous vent No. 1	1.090 in. dia	--	N/A
Continuous vent No. 2	1.090 in. dia	--	N/A
Continuous vent purge	1 scfm with 3,200 psid	--	Sintered
LH_2 fill and drain valve purge	15 scim with 3,200 psid	--	Sintered
LOX fill and drain valve purge	15 scim with 3,200 psid	--	Sintered
LH_2 chilldown valve purge	66 scfm with 1,600 psid	--	Sintered
LOX tank pressurization module, heat exchanger primary	0.2189 in. dia	0.87	0.0329
LOX tank pressurization module, heat exchanger bypass	0.1860 in. dia	0.87	0.02272
LH_2 tank pressurization--step mode (All three orifices used for acceptance firing only)	--	--	0.1392*

*Discharge coefficient and effective area are calculated for overcontrol and step orifices in combination with the undercontrol orifice.

Table 3-1 (Continued)

DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in^2)
LH_2 tank pressurization module (Overcontrol-second burn)	0.2058 in. dia	– *	0.1110**
LH_2 tank pressurization module normal (Under-control)	0.3283 in. dia	*	0.0828
LH_2 tank pressurization module control (Over-control-first burn)	0.2056 in. dia	*	0.1110**
LH_2 tank pressurization module outlet	0.3124 in. dia	0.82	0.0666
O_2-H_2 burner LH_2 supply valve purge	15 scim with 3,200 psid	--	Sintered
LH_2 tank nonpropulsive vent purge	1 scfm with 3,200 psid	--	Sintered
LH_2 tank nonpropulsive vent No. 1	2.180 in. dia	--	N/A
LH_2 tank nonpropulsive vent No. 2	2.180 in. dia	--	N/A
LOX chilldown pump purge	37 scim with 475 psid	--	Sintered
LOX sensing line purge	1 scfm with 3,200 psid	--	Sintered
O_2-H_2 burner GH_2 balance, injector No. 1	0.510 in. dia	--	--
O_2-H_2 burner GH_2 balance, injector No. 2	0.510 in. dia	--	--
O_2-H_2 burner LH_2 tank pressurization coil outlet	0.221 in. dia	--	0.03375

*Not recorded during calibration
**Discharge coefficient and effective area are calculated for overcontrol and step orifices in combination with the undercontrol orifice.

Table 3-1 (Continued)

DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in^2)
LOX tank vent and relief valve purge	65 scfm with 3,200 psid	--	Sintered
O_2-H_2 burner LH_2 tank pressurization coil helium inlet balance	0.120 in. dia	0.88	0.00971
O_2-H_2 burner LOX tank pressurization coil outlet	0.089 in. dia	0.895	0.00568
LOX tank ambient repressurization module outlet	0.116 in. dia	--	0.00888
Engine purge control module	6 scfm	--	0.00028
<u>Console A</u>			
All console A stage bleeds	Variable	--	--
Pressure actuated valve and main-stage pressure switch supply	1.2 scfm	--	Sintered
J-box inerting supply	0.013 in. dia	--	--
LH_2 system checkout supply	1.2 scfm	--	Sintered
LOX system checkout supply	2.0 scfm	--	Sintered
LH_2 tank and umbilical purge supply	0.260 in. dia	0.88	0.0468
Pressure switch checkout-Low pressure	1.2 scfm	--	Sintered
Pressure switch checkout-High pressure	0.044 in. dia	0.91	0.00139

Table 3-1 (Continued)

DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in^2)
LH_2 tank repressurization supply	Union	--	--
Console GN_2 inerting supply	0.013 in. dia	--	--
Console B			
All console B stage bleeds	Variable	--	--
LOX tank repressurization supply	0.114 in. dia	0.88	0.00898
Turbine start sphere supply	Union	--	--
LOX tank prepressurization supply	0.096 in. dia	0.94	0.00680
Console GN_2 inerting supply	Variable	--	--
Engine control helium sphere supply	0.125 in. dia	0.83	0.0102
LH_2 tank prepressurization supply	0.161 in. dia	0.83	0.0169
Thrust chamber jacket purge and childown supply	0.072 in. dia	0.91	0.00370
LOX tank and umbilical purge supply	0.302 in. dia	0.89	0.0635
J-box inerting supply	0.013 in. dia	--	--
Turbine start sphere supply vent	0.081 in. dia	0.83	0.00479
LOX tank auxiliary pressure	0.2517 in. dia	0.94	0.0465
LH_2 tank auxiliary pressure	0.385 in. dia	0.91	0.1060

TABLE 3-2

S-IVB-508 STAGE PRESSURE SWITCH DATA

Name	Part No. and Serial No.	Specification (psia)			Prefiring (psia)		
		Pickup	Dropout	Deadband	Pickup*	Dropout*	Deadband*
LH2 Tank							
First burn and flight control	1B52624-511 S/N 30	31.5 max	27.8 min	0.5 min	30.68	28.59	2.09
Second burn, ground fill, and prepressurization	1B52624-511 S/N 31	31.5 max	27.8 min	0.5 min	30.13	28.35	1.78
LOX Tank							
LOX flight control and ground fill	1B52624-515 S/N 45	41.0 max	37.5 min	0.5 min	40.42	38.99	1.43
LOX Pressurization System							
Cold helium regulator backup	1B52624-519 S/N 48	467.5 ±23.5	362.5 ±33.5	--	474.29	381.37	--
Pneumatic Power System							
Control helium regulator backup	1B52624-517 S/N 21	600 ±21	490 ±31	--	601.17	494.74	--
Engine pump purge	1B52623-515 S/N 20	136 max	99 min	3.0 min	120.72	108.29	12.43
J-2 Engine System							
Mainstage OK No. 1	308390 S/N 25579A	515 ±36	Pickup minus 75 +56, -31	--	506.10	447.40	57.70
Mainstage OK No. 2	308390 S/N 25560A	515 ±36	Pickup minus 75 +56, -31	--	516.24	444.75	71.48
O2-H2 Burner							
LOX tank repressurization	1B52624-519 S/N 47	467.5 ±23.5	362.5 ±33.5	--	475.69	384.40	--
LH2 tank repressurization	1B52624-519 S/N 55	467.5 ±23.5	362.5 ±33.5	--	471.70	375.86	--

* The values listed are the average of three actuations.

FOLDOUT FRAME 1

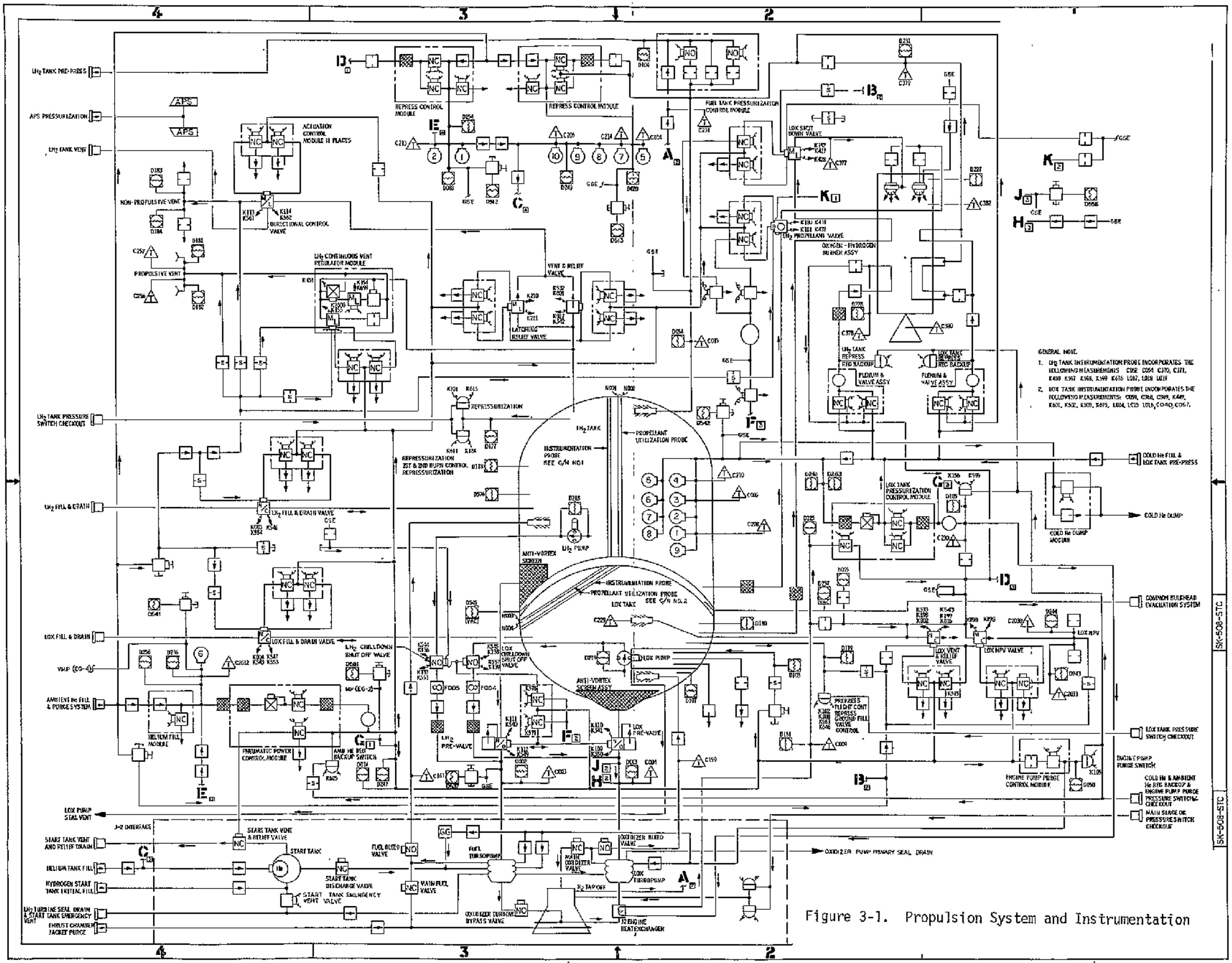


Figure 3-1. Propulsion System and Instrumentation

FOLDOUT FRAME 2

SECTION 4

TEST OPERATIONS

4. TEST OPERATIONS

The S-IVB-508 stage was the eighth of the basic S-IVB/V series to be successfully acceptance tested. The acceptance firing was preceded by an O2-H2 burner firing and an ambient repressurization test. Details of the countdown and checkout (precountdown) activities are presented in the following paragraphs. Significant events occurred at the following times:

Event	Time (PST)
O2-H2 burner firing initiation	11.18:19.000
Simulated liftoff	14.13:44.000
Engine start command	14.22:15.695
Engine cutoff command	14.29:55.684

4.1 Countdown Operations

The acceptance firing, countdown 614116, was a full duration J-2 engine firing initiated on 18 February 1969 at 0800 PST. The countdown proceeded normally until computer problems caused a 24-hour hold. After the count was resumed, several unexpected events were encountered (see paragraph 4.3). The acceptance firing was satisfactorily completed on 20 February 1969.

Except for the deviations necessitated by a single J-2 engine burn, the performance of an O2-H2 burner firing, and the ambient repressurization test, the countdown conformed to the sequence intended for use at Kennedy Space Center. Significant events during these operations are listed in tables 4-1, 4-2, and 4-3. The propulsion operations were performed in the following sequence:

a. Propellants were loaded to the 68 percent level.
b. LOX and LH2 tank vent relief test was performed.
c. The continuous vent valve was functionally tested.
d. An O2-H2 burner firing was performed.
e. The ambient repressurization system was functionally tested.
f. The LOX and LH2 tanks were reloaded to the 100 percent level.
g. The terminal countdown and J-2 engine firing were performed.

The tank vent/relief tests were accomplished during the propellant loading test and were not repeated during the acceptance firing countdown. The vent and relief valves vented at the following pressures:

Valve	Pressure (psia)		
LOX NPV	43.1	43.1	42.9
LOX vent and relief	*	44.1	44.0
LH2 NPV	32.7	32.6	32.6
LH2 latching vent and relief	32.7	32.6	32.6

* The LOX NPV cracked at 43.1 psia, and the tank pressure was not taken up to the 44.0 psia level.

The firing of the restartable O2-H2 burner was initiated at 11.18:19 PST and proceeded normally through burner shutdown. The burner firing was 460 seconds in duration, as planned.

4.1.1 Cryogenic Loading

Setups for LOX loading began at 0618 PST on 20 February, and both tanks were loaded to the 68 percent level by 0848 PST. The on-stand inspection was then accomplished, and the burner and ambient repressurization tests were performed. The tanks were then reloaded to the 100.5 percent level.

4.1.2 Terminal Countdown

The terminal countdown was initiated at 13.53:15 PST (T -20:30 minutes). The count proceeded smoothly through J-2 engine cutoff which was initiated by the LH2 depletion sensor at SLO +972 seconds. Mainstage duration was 456.3 seconds.

4.2 Checkout

After the S-IVB-508 stage was assembled at the McDonnell-Douglas Astro-Astronautics Company in Huntington Beach, it was subjected to a complete stage checkout including an all-systems test. It was then modified and shipped to the Sacramento Test Center (STC). It arrived at STC on 31 December 1968 and was installed in Complex Beta Test Stand III on 3 January 1969. The modification program continued concurrently with stage checkout. All modifications were completed before the integrated systems test which was satisfactorily completed on 7 February.

A practice countdown was conducted on 12 and 13 February for software verification and countdown crew training. The "Ready for Acceptance Firing" milestone was met on 17 February, 4 days after satisfactory completion of the simulated static firing test. The prefiring and postfiring checkouts were performed in accordance with the established handling and checkout procedures.

4.3 Countdown Problems

The countdown proceeded quite smoothly except for computer problems which caused a 24-hour hold; however, several unexpected events did occur.

a. Two safety item monitor data amplifiers could not be adjusted within tolerance during redline checks. Both were replaced.

b. The forward interstage backup GN2 panel gage was overpressurized and damaged. A Heise gage was installed to monitor this function for the remainder of the countdown.

c. During the integrated systems test preparations, a computer check sum error occurred, and test tapes could not be read into the computer. A 24-hour hold in the countdown was called for troubleshooting. The problem disappeared and could not be isolated. After appropriate preplanning, the countdown was resumed, and the problem did not recur.

d. The upper low-pressure fuel duct lost its vacuum prior to the firing. The post-test examination disclosed that, because of a leaking vacuum valve, the duct contained nitrogen. It was replaced.

   The lower low-pressure fuel duct was found to be cracked in the middle bellows, and it was also replaced.

e. During the first critical components cycling of the cold helium shutoff valves, the cold helium regulator discharge pressure (D0105) rose normally, then dropped to an abnormally low value (100 to 125 psia) for the duration of the cycle. Cold helium sphere pressure was approximately 800 psia. The I-3 module regulated properly during the firing, but not during the critical components test before the firing. The module was replaced after the firing.

f. Transducer D0577, LOX tank ullage pressure, failed during the countdown and was replaced.

g. Although transducer C0419, O2-H2 burner chamber dome temperature, functioned properly during the burner test, it failed during the acceptance firing. It was replaced postfire.

h. The engine shutoff, which was to occur at 1 percent LOX or 2 percent LH2, was preempted by an LH2 depletion sensor cutoff which accomplished engine shutdown and securing through a planned alternate program subroutine.

i. Transducer D0002, fuel pump inlet pressure, failed during the engine cutoff transient. It was replaced.

j. During conditioning of the LH2 tank ullage between 18.6 and 20.1 psia for burner start by cycling the LH2 vent valve, an unusually large number of extraneous LH2 vent valve open talkback (K0542) cycles were recorded; approximately 1,050 cycles plus an unknown number not recorded due to saturation of DER buffer. Recording of these cycles exhausted the DER paper, and reloading of the DER delayed the countdown 8 minutes.

k. Thrust chamber temperature reached the start box at T +240 seconds. The nominal time for this event during recent tests has been near T -0 (simulated liftoff). The thrust chamber chilldown rate was slower than usual from initiation of chilldown to the end of prepressurization; thereafter, the rate was normal. Although this phenomenon caused no perturbations to the countdown, it is under investigation.

4.4 Atmospheric Conditions

The following atmospheric conditions prevailed during the countdown:

Time (PST)	0855	1624
Wind speed (knots)	6	14 to 20
Wind direction	South	Southwest
Barometric pressure (in. Hg)	29.89	29.78
Ambient temperature (deg F)	47	49
Dew point (deg F)	45	41

TABLE 4-1

O2-H2 BURNER SEQUENCE OF EVENTS

Time (sec)	Meas. No.	Event
-8.557	K0532	LH2 tank vent valve closed
0		Start burner operation ignition sequence (11:18:19.626 PST, O2-H2 LH2 propellant valve open)
1.975	K0427	O2-H2 LOX propellant valve open
2.116	K0452	LH2 tank vent orifice and relief reset
2.136	K0699	LH2 tank vent relief overboard valve closed
2.222	K2400	LH2 tank vent orifice bypass valve closed
5.314	K0437	O2-H2 burner system relay reset
8.000	K0438	O2-H2 voting circuit enabled
8.114	K0443	LH2 tank repressurization valve energized
8.327	K0444	LOX tank repressurization valve energized
178.665	K0444	LOX tank repressurization valve closed
182.569	K0443	LH2 tank repressurization valve closed
182.572	K0616	LH2 tank overpressurization pressure switch energized
209.081	K0519	LOX chilldown pump/inverter energized
214.136	K0512	LH2 chilldown pump/inverter energized
219.311	K0576	LH2 and LOX prevalve closed - energized
410.006	K0524	LH2 tank flight pressure valve energized
410.006	K0523	LH2 tank step pressurization valve energized
456.772	K0432	LH2 propellant valve closed
456.918	K0441	LH2 and LOX repressurization system reset
456.919	K0438	O2-H2 voting circuit disabled
457.113	K0452	LH2 tank vent orifice and relief reset off
457.513	K0440	LH2 and LOX repressurization mode - ambient
458.726	K0437	O2-H2 burner system relay reset
460.307	K0428	O2-H2 LOX propellant valve closed
520.262	K0544	LH2 chilldown shutoff valve open

Table 4-1 (Continued)

Time (sec)	Meas. No.	Event
521.459	K0541	LOX prevalve open
521.686	K0540	LH2 prevalve open
529.389	K0641	LH2 chilldown pump relay reset
529.599	K0644	LOX chilldown pump relay reset
530.871	K0621	Hydraulic auxiliary pump flight relay reset

TABLE 4-2

AMBIENT REPRESSURIZATION SEQUENCE

Time (sec)	Meas. No.	Event
-110.886	K0543	LOX tank vent valve closed
0	K0444	Start of ambient repressurization (LOX tank repressurization valve open, 11:29:27.100 PST)
4.560	K0699	LH2 tank vent relief overboard valve closed
4.646	K2400	LH2 tank vent orifice bypass closed
20.519	K0443	LH2 tank repressurization valve open
44.070	K0616	LH2 tank overpressure pressure switch energized
45.474	K0443	LH2 tank repressurization valve closed
84.102	K0444	LOX tank repressurization valve closed
84.104	K0563	LOX tank overpressure pressure switch energized
118.242	K0516	LH2 tank vent valve open
167.5*	K0466	LOX tank NPV valve open

* Approximate time. Exact time is not available due to DER saturation.

TABLE 4-3

ACCEPTANCE FIRING SEQUENCE

Time (Sec)	Meas. No.	Event
-874.073	K2881	Engine start tank purge supply closed
-870.009	K2853	Start engine start tank chilldown and fill
-407.930	K2888	Start engine thrust chamber chilldown
-329.968	K3885	Start tank vent closed
-325.056	K2852	End engine start tank fill
-298.969	K2892	End engine control bottle fill
-298.718	K0512	LH2 chilldown pump on
-288.692	K0519	LOX chilldown pump on
-283.661	K0576	LOX and LH2 prevalve closed command
-283.550	K0540	LH2 prevalve open position drop-out
-283.537	K0541	LOX prevalve open position drop-out
-283.306	K0549	LH2 prevalve closed position pick-up
-283.244	K0550	LOX prevalve closed position pick-up
-208.918	K2424	LOX NPV latched
-165.372	K0533	LOX vent valve closed
-163.758	K0571	Start LOX tank prepressurization
-153.412	K0571	End LOX tank prepressurization
-146.119	K0571	Start LOX tank prepressurization make-up cycle
-145.282	K0571	End LOX tank prepressurization make-up cycle
-95.784	K0532	LH2 tank vent valve closed
-94.170	K2897	Start LH2 tank prepressurization
-51.692	K2897	End LH2 tank prepressurization
-7.856	K3705	Cold helium supply vent opened
-7.801	K2870	LH2 tank prepressurization supply vent open
0		Simulated Liftoff (14:13:44.000 PST)
488.799	K2889	Engine thrust chamber chilldown terminated
507.697	K0576	LH2 and LOX prevalve open command
508.655	K0549	LH2 prevalve closed position drop-out
508.474	K0550	LOX prevalve closed position drop-out
509.292	K0571	Open cold helium shutoff valves
509.837	K0541	LOX prevalve open pick-up

Table 4-3 (Continued)

Time (Sec)	Meas. No.	Event
510.087	K0540	LH2 prevalve open pick-up
510.963	K0519	LOX chilldown pump off
511.055	K0512	LH2 chilldown pump off
511.693	K0556	Engine start command
511.695	K0531	Engine control helium valve opened
511.758	K0627	LOX ASI valve opened
511.762	K0632	Main LH2 valve started to open
511.810	K0557	LH2 bleed valve closed
511.831	K0458	Main LH2 valve opened
511.836	K0466	LOX tank vent valve opened
511.843	K0558	LOX bleed valve closed
512.827	K0536	Start tank discharge valve open command
512.956	K0695	Start tank discharge valve starts to open
513.039	K0460	Start tank discharge valve open
513.279	K0536	Start tank discharge valve close command
513.365	K0633	MOV starts to open
513.378	K0631	GG valve started to open
513.421	K0460	Start tank valve started to close
513.507	K0457	GG valve open
513.634	K0695	Start tank valve closed
514.676	K0524	LH2 tank flight pressure valve close command
514.676	K0523	LH2 tank step press valve close command
515.442	K0466	LOX tank vent valve closed
515.515	K0459	MOV open
516.012	K0532 K2431	LH2 tank vent valve and latching vent valve began relieving
531.402	K0532	LH2 vent valve closed
532.671	K2432	J-2 heat exchanger bypass valve open disabled
768.845	K2431	LH2 latching vent valve closed
861.859	K0524 K0523	LH2 tank flight pressurization second burn mode initiated
921.850	K0523 K0524	LH2 tank step pressurization initiated

Table 4-3 (Continued)

Time (Sec)	Meas. No.	Event
922.045	K0577	LH2 and LOX chilldown shutoff valve closed command
922.197	K0544	LH2 chilldown shutoff valve open drop-out
922.203	K0545	LOX chilldown shutoff valve open drop-out
922.246	K0552	LOX chilldown shutoff valve closed pick-up
922.248	K0551	LH2 chilldown shutoff valve closed pick-up
927.866	K0532	LH2 vent valve relieving
929.204	K2431	LH2 tank latching vent valve closed position drop-out
971.684	K0522	Engine cutoff command

SECTION 5

SEQUENCE OF EVENTS

5. SEQUENCE OF EVENTS

The S-IVB-508 acceptance firing sequence of events is presented in table 5-1. The two time bases used in this table are as follows:

First O_2-H_2 Burner Ignition Sequence	1118:19.000 hr PST
Simulated Liftoff for J-2 Engine Firing	1413:44.000 hr PST

The data sources were the Digital Events Recorder (DER/CAT 57) and the PCM/FM System (CAT 42). Accuracies of the listed events are as follows:

Data Source	Accuracies
Digital Events Recorder (DER/CAT 57)	+0, -1 ms
PCM/FM	
Discrete Bilevel (CAT 42)	
Direct Inserted	+0, -9 ms
Submultiplexed	+0, -84 ms

TABLE 5-1 (Sheet 1 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Launch Automatic Sequence Start (J-2 Eng. Firing Phase)					
S-IVB Engine Cutoff	12	K3890	-478.009		
Aux Hyd Pump Flt Mode On	28	K3890	-476.917		
Aux Hyd Pump Flt Rel Reset - Off		K0621	-476.913		
Aux Hyd Pump Power On		K0513	-476.830		
Eng St Tk Dump Close		K3885	-329.968		
LH_2 Chilldown Pump On	58	K3890	-298.726		
LH_2 C/D Pump Rel Reset - Off		K0641	-298.720		
LH_2 C/D Pump Inverter On		K0512	-298.718		
LOX Chilldown Pump On	22	K3890	-288.701		
LOX C/D Pump Rel Reset - Off		K0644	-288.693		
LOX C/D Pump Inverter On		K0519	-288.692		
LOX & LH_2 Prevalve Close Command - On		K0576	-283.661		
LH_2 Prevalve Open Indication - Off		K0540	-283.550	K0111	-283.542
LOX Prevalve Open Indication - Off		K0541	-283.537	K0109	-283.459
LH_2 Prevalve Closed Indication - On		K0549	-283.306	K0112	-283.292
LOX Prevalve Closed Indication - On		K0550	-283.244	K0110	-283.209

TABLE 5-1 (Sheet 2 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Heat Exchanger Bypass Valve Control Disable (Preflight Command Only)	51	K3890	-209.069		
Heat Exchanger Bypass Disable		K2432	-209.060		
LOX Tk NPV Vlv Latch Open Off	45	K3890	-208.927		
LOX Tk Vent & NPV Latch Rst On		K2424	-208.918		
LOX Tank Vent Valve Open Command - Off		K0575	-165.819		
LOX Tank Vent Valve Closed Indication - On		K0533	-165.375	K0002	-165.297
Cold He Shutoff Valve Open Command		K3802	-163.765		
Cold He Shutoff Valve Open Indication		K0571	-163.758		
LOX Tk Overpress P/S Ener		K0563	-153.417	K0102	-153.382
He Cold Sol Vlv Opn De-Ener		K0571	-153.412		
LOX Tk Overpress P/S De-Ener		K0563	-146.126	K0102	-146.048
He Cold Sol Vlv Opn Ener		K0571	-146.119		
He Cold Sol Vlv Opn De-Ener		K0571	-145.282		
LH_2 Tank Vent Valve Close Command - On		K0516	-96.316		
LH_2 Tank Vent Valve Closed Indication - On		K0532	-95.784	K0001	-95.810

TABLE 5-1 (Sheet 3 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Tank Fill & Drain Bst Close - On		K3845	-84.456		
LOX Tank Fill & Drain Open - Off		K0547	-83.837		
LOX Tank Fill & Drain Closed Indication - On		K0553	-83.336	K0004	-83.310
LOX Tank Fill & Drain Bst Close - Off		K3845	-82.408		
LH_2 Tank Fill & Drain Bst Close - On		K3831	-82.357		
LH_2 Tank Fill & Drain Open - Off		K0546	-81.704		
LH_2 Tank Fill & Drain Closed Indication - On		K0554	-81.200	K0003	-81.143
LH_2 Tank Fill & Drain Bst Close - Off		K3831	-80.308		
Aft Bus 1 Transfer Internal Indication		K0622	-49.147		
Aft Bus 2 Transfer Internal Indication		K0623	-48.887		
Fwd Bus Transfer Internal		K0639	-48.642		
LH_2 Tank Vent Dir Gnd Position Off		K0561	-26.264	K0113	-26.221
LH_2 Tank Vent Dir Flight Position On		K0562	-26.187	K0114	-26.138
R/S 1 PD Cmd Inhibit Off Indication		K0662	-7.774		
R/S 2 PD Cmd Inhibit Off Indication		K0661	-7.745		

TABLE 5-1 (Sheet 4 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57) MEAS. NO.	DIGITAL EVENT RECORDER (CAT 57) TIME (sec)	PCM/FM SEQUENCE (CAT 42) MEAS. NO.	PCM/FM SEQUENCE (CAT 42) TIME (sec)
Simulated Liftoff (T_0)*			000.000		
T/M Calibration On	62	K3890	116.712		
T/M Calibration Off	63	K3890	117.826		
Eng Pump Prg Cont Valve Enable On	24	K3890	330.544		
Eng Pump Prg Sol Valve Energized		K0566	330.556		
Eng Cutoff Arm - Observer		K5811	333.984		
Eng Pump Prg Cont Valve Enable Off	25	K3890	450.652		
Eng Pump Prg Sol Valve De-energized		K0566	450.665		
T/M Calibration On	62	K3890	451.999		
T/M Calibration Off	63	K3890	453.125		
Charge Ullage Ignition On	54	K3890	507.555		
Ullage Rkt Pilot Relays Rst Off		K0673	507.561		
LH_2 & LOX Prevalve Open Command - On		K0576	507.697		
LOX Prevalve Closed Indication - Off		K0550	508.474	K0110	508.505
LH_2 Prevalve Closed Indication - Off		K0549	508.655	K0112	508.672
LOX Tk Flt Press Sys On	103	K3890	509.279		
LOX Prevalve Open Indication - On		K0541	509.837	K0109	509.838

*T_0 = 1413:44.00

TABLE 5-1 (Sheet 5 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Prevalve Open Indication - On		K0540	510.087	K0111	510.038
LOX Chilldown Pump Off	23	K3890	510.958		
LOX C/D Pump Inverter Off Indication		K0519	510.963		
LOX C/D Pump Rel Reset Indication		K0644	510.966		
LH_2 C/D Pump Off	59	K3890	511.050		
LH_2 C/D Pump Inverter Off Indication		K0512	511.055		
LH_2 C/D Pump Rel Reset Indication		K0641	511.057		
S-IVB Engine Cutoff Off	13	K3890	511.228		
Engine Cutoff Ind - Sw Sel Reset		K0418	511.234	K0140	511.314
Engine Cutoff Indicator - De-energized		K0522	511.240		
Aft Separate Simu 1 On		K4790	511.291		
Aft Separate Simu 2 On		K5714	511.323		
Fire Ullage Ign On	56	K3890	511.384		
Ullage Rkt Ign PS 1 Indication				K0176	511.438
Ullage Rkt Ign PS 2 Indication				K0177	511.438
S-IVB Engine Start On	9	K3890	511.689		
Engine Start Command Rel Rst Off		K0634	511.693		

TABLE 5-1 (Sheet 6 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Engine Start Command On		K0556	511.693	K0021	511.695
Eng Ign Ph Cont Sol Ener		K0535	511.694	K0006	511.695
Eng Spark T/C Sys On		K0454	511.694	K0010	511.695
Eng Spark GG Sys On		K0455	511.694	K0011	511.695
Eng Cont He Sol Valve Ener		K0531	511.695	K0007	511.695
Eng Ready Sig Off		K0530	511.697	K0012	511.763
Eng ASI LOX Valve Open		K0627	511.758		
Eng Main LH_2 Vlv Cls - Off		K0632	511.762		
Eng LH_2 Bld Valve Cls - On		K0557	511.810		
Eng Main LH_2 Vlv Open - On		K0458	511.831	K0118	511.847
Eng LOX Bld Vlv Cls - On		K0558	511.843		
Eng Ign Detected		K0537	511.966	K0008	511.970
Aft Separate Simu 1 Off		K4790	512.038		
Aft Separate Simu 2 Off		K5714	512.048		
Fuel Inj Temp OK Bypass	11	K3890	512.817		
Fuel Inj Temp OK Bypass Reset		K0446	512.824		
Engine Start Tk Disch Sol Ener		K0536	512.827	K0096	512.828
S-IVB Engine Start Off	27	K3890	513.026		

TABLE 5-1 (Sheet 7 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Engine Start Command Rel Rst		K0634	513.029		
Engine Start Command Off		K0556	513.031	K0021	512.053
Eng St Tk Disch Vlv Opn - On		K0460	513.039	K0122	513.097
Eng St Tk Disch Sol Ener - Off		K0536	513.279	K0096	513.287
Eng M/S Cont Sol Ener - On		K0538	513.279	K0005	513.278
Eng Main LOX Vlv Cls - Off		K0633	513.365		
Eng GG Vlv Cls - Off		K0631	513.378		
Eng St Tk Disch Vlv Opn - Off		K0460	513.421	K0122	513.430
Eng GG Vlv Opn - On		K0457	513.507	K0117	513.513
Eng LOX Turb Byp Vlv Open - Off		K0461	513.536	K0124	513.605
Eng St Tk Disch Vlv Cls - On		K0695	513.634		
Eng LOX Turb Byp Vlv Closed - On		K0463	513.749	K0125	513.772
First Burn Relay On	68	K3890	514.667		
First Burn Press Cont Vlv Sol Ener		K0524	514.676		
First Burn Step Press Cont Vlv Ener		K0523	514.676		
Eng M/S OK Press Sw-1		K0610	514.914	K0014	514.996

TABLE 5-1 (Sheet 8 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng M/S OK P/S-1 Pressurized		K0572	514.915	K0158	514.954
Eng M/S OK Press Sw Pick-up (No)		K0412	514.916		
Eng M/S OK Press Sw Pick-up (No)		K0685	514.916		
Eng M/S OK P/S-2 Pressurized		K0573	514.949	K0159	514.954
Eng M/S OK P/S-2 Pressurized				K0157	514.954
Eng Main LOX Vlv Open		K0459	515.515	K0120	515.596
Eng Spark GG Sys - Off		K0454	516.580	K0010	516.585
Eng Spark T/C Sys - Off		K0455	516.580	K0011	516.585
PU Activate On	5	K3890	517.854		
PU Activated		K0507	517.859		
Chg Ullage Jett On	55	K3890	519.335		
Fire Ullage Jett On	57	K3890	521.869		
EBW Fire 1 PS				K0149	521.946
EBW Fire 2 PS				K0150	521.946
Fuel Inj Temp OK Bypass Reset	16	K3890	523.089		
Eng LH_2 Inj Temp Byp Rst		K0446	523.089		
Ullage Chg Reset	88	K3890	525.262		
Ullage Firing Reset	73	K3890	525.466		
UR Pilot Relays Rst		K0673	525.475		

TABLE 5-1 (Sheet 9 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Ht Exch Valve Control Enable	50	K3890	532.665		
R/S Tone 2 EBW Arm & ECO		K5758	536.107		
R/S 2 Arm & ECO Cmd Rcvd		K0659	536.214		
R/S 1 Arm & ECO Cmd Rcvd		K0660	536.217		
R/S 2 PD EBW FU Pwr On		K0651	536.217		
R/S 1 PD EBW FU Pwr On		K0650	536.220		
R/S 2 EBW Arm & ECO On		K0692	536.221		
R/S 1 EBW Arm & ECO On		K0693	536.224		
R/S 2 Arm & ECO Cmd Rcvd Off		K0659	536.241		
R/S 1 Arm & ECO Cmd Rcvd Off		K0660	536.245		
R/S Tone 2 EBW Arm & ECO Off		K5758	536.379		
R/S Tone 1 PD Cmd On		K5757	539.476		
R/S 2 PD Cmd Rcvd On		K2405	539.582	K0142	539.603
R/S 1 PD Cmd Rcvd On		K2404	539.585	K0141	539.603
R/S 2 PD Cmd Rcvd Off		K2405	539.610		
R/S 1 PD Cmd Rcvd Off		K2404	539.614		
R/S Tone 1 PD Cmd Off		K5757	539.724		
R/S Tone 6 Sys Off Cmd - On		K5759	542.798		
R/S 2 Sys Off Cmd Rcvd - On		K0679	542.899		
R/S 2 PD EBW FU Pwr Off		K0651	542.901		

TABLE 5-1 (Sheet 10 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
R/S 2 Rcvr Pwr Off		K0678	542.901		
R/S 2 Sys Off Cmd Rcvd - Off		K0679	542.902		
R/S 1 Sys Off Cmd Rcvd - On		K0681	542.903		
R/S 1 Sys Off Cmd Rcvd Off		K0681	542.904		
R/S 1 PD EBW FU Pwr Off		K0650	542.904		
R/S 1 Rcvr Pwr Off		K0680	542.904		
R/S Tone 6 Sys Off Cmd - Off		K5759	543.051		
Aux Hyd Pmp Flt Mode Off	29	K3890	656.794		
Aux Hyd Pmp Flt Rel Rst - Off		K0621	656.798		
Aux Hyd Pmp On Ener - Off		K0513	657.046		
Aux Hyd Pmp Flt Mode On	28	K3890	706.892		
Aux Hyd Pmp Flt Rel Reset - Off		K0621	706.895		
Aux Hyd Pmp Power On		K0531	706.981		
First Burn Relay Off	69	K3890	861.852		
Fuel Tank Press Cont Vlv Sol De-ener		K0524	861.859		
Fuel Tank Step Press Cont Vlv Sol De-ener		K0523	861.860		
Second Burn Relay On	32	K3890	861.964		
LH_2 Tk Step Pres Vlv Ener		K0523	861.972		

TABLE 5-1 (Sheet 11 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Fuel Tk Press Cont Vlv Sol Ener		K0524	861.972		
PU Active Off	6	K3890	862.054		
PU Hardover On	17	K3890	862.151		
Second Burn Relay Off	33	K3890	921.843		
Fuel Tk Press Cont Vlv Sol De-ener		K0524	921.850		
LH_2 Tk Step Pres Vlv Ener		K0523	921.850		
PU Position Hardover Off	18	K3890	921.934		
LH_2 & LOX C/D Shutoff Close Ener - On		K0577	922.045		
LH_2 C/D Shutoff Valve Open - Off		K0544	922.197	K0137	922.203
LOX C/D Shutoff Valve Open - Off		K0545	922.203	K0138	922.211
LOX C/D Shutoff Valve Closed - On		K0552	922.246	K0139	922.295
LH_2 C/D Shutoff Valve Closed - On		K0551	922.248	K0136	922.286
Point Level Sensor Arming	97	K3890	966.256		
Eng Pump Purge Cont Vlv Enable On	24	K3890	966.355		
Eng Pump Prg Sol Vlv Ener - On		K0566	966.367	K0105	967.901
Eng Cutoff Lock-in Ind - On		K0539	971.681	K0013	971.741

TABLE 5-1 (Sheet 12 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Ign Ph Cont Sol Ener - Off		K0535	971.682	K0006	971.681
Eng Cutoff Ind - Veh Ener - On		K0522	971.684		
Eng M/S Cont Sol Ener - Off		K0538	971.684	K0005	971.681
Eng Cutoff Ind - Non Prog - On		K0419	971.685		
Eng GG Vlv Open - Off		K0457	971.715	K0117	971.741
O_2-H_2 Burner Sys Rel Rst		K0437	971.735		
Eng Main LOX Vlv Open - Off		K0459	971.771	K0120	971.825
Eng GG Vlv Cls - On		K0631	971.773		
Eng Main LH_2 Vlv Open - Off		K0458	971.801	K0118	971.825
Eng M/S OK P/S-2 Depressurized		K0573	971.860	K0159	971.933
Eng M/S OK P/S-1 Depressurized		K0572	971.865	K0158	971.933
Eng M/S OK Press Sw No. 1 - Off		K0610	971.866	K0014	971.891
Eng Thrust OK 2		K0412	971.867		
Eng Thrust OK 1		K0685	971.868		
Eng Main LOX Vlv Cls - On		K0633	971.885		
Eng LOX Turb Byp Vlv Cls - Off		K0463	971.954	K0125	972.000

TABLE 5-1 (Sheet 13 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Main LH_2 Vlv Cls - On		K0632	971.979		
Eng Pmp Prg Cont Vlv Enable On	24	K3890	972.022		
Fwd Bus Transfer External Indication - Off		K0639	972.121		
Aft Bus 1 Transfer External Indication		K0622	972.302		
Eng LOX Turb Byp Vlv Opn		K0461	972.403	K0124	972.416
Aft Bus 2 Transfer External Indication		K0623	972.479		
Eng Cont He Sol Vlv Ener - Off		K0531	972.674	K0007	972.681
Eng Cutoff Lock-in Ind - Off		K0539	972.677	K0013	972.741
Eng Ready Sig On		K0530	972.680	K0012	972.741
LH_2 & LOX Prevalve Closed Command - On		K0576	973.149		
LH_2 Prevlv Open Indication - Off		K0540	973.256	K0111	973.316
LOX Prevlv Open Indication - Off		K0541	973.272	K0109	973.316
LH_2 Prevlv Cls - On		K0549	973.494	K0112	973.556
LOX Prevalve Close - On		K0550	973.568	K0110	973.650
S-IVB Engine Start Off	27	K3890	973.789		
He Cold Sov Cls - On		K3802	973.882		
He Cold Sov Opn - Ener - Off		K0571	973.888		

TABLE 5-1 (Sheet 14 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
S-IVB Engine Cutoff	12	K3890	973.937		
Engine Cutoff Ind - Sw Sel		K0418	973.941		
LOX Tk Press Shutoff Vlvs Cls On	79	K3890	974.034		
First Burn Relay Off	69	K3890	974.157		
Second Burn Relay Off	33	K3890	974.253		
LOX Tank Flight Press System Off	104	K3890	974.349		
LOX Chilldown Pmp Off	23	K3890	974.525		
LH_2 Chilldown Pmp Off	59	K3890	974.622		
Point Level Sensor Disarming	98	K3890	976.031		
Fuel Inj Temp OK Bypass Reset	16	K3890	977.317		
Ullage Chg Reset	88	K3890	977.731		
Ullage Firing Reset	73	K3890	977.827		
T/M Calibration Off	63	K3890	977.950		
Inflight Relays - Off	49	K3890	978.046		
Regular Calibration - Off	47	K3890	978.169		
Heat Exchanger Valve Control Enab	50	K3890	978.456		
Eng Cont Btl Dmp Opn - On		K3817	978.557		
Aux Hyd Pmp Flt Mod Off	29	K3890	1087.216		

TABLE 5-1 (Sheet 15 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Aux Hyd Pmp Flt Rel Rst		K0621	970.002		
Aux Hyd Pmp On Ener No		K0513	1087.472		
Eng Cutoff Cmd - C/T Pwr Off		K4796	1124.660		
Eng Cutoff Cmd - GSE Pwr Off		K4797	1121.686		
S-IVB Eng Cutoff Off	13	K3890	1124.756		
Eng Cutoff Ind - Sw Sel - Off		K0418	1124.762		
LOX Tk Press Shutoff Vlvs Cls Off	80	K3890	1124.926		
LH_2 Tk Vnt Dir Flt Pos - Off		K0562	1131.456		
LH_2 Tk Vnt Dir Gnd Pos - On		K0561	1131.517		
T/M Prelaunch C/O Grp On Command		K0406	1213.515		
T/M Prelaunch C/O Grp On Indication		K0408	1213.564		
T/M Prelaunch C/O Grp On Comm - Off		K0406	1213.691		
Inflight Relay On	48	K3890	1213.869		
Reg. Cal. On	46	K3890	1213.958		
Inflight Relay Off	49	K3890	1219.077		
Reg. Cal. Off	47	K3890	1219.173		
T/M Cal. On	62	K3890	1219.277		

TABLE 5-1 (Sheet 16 of 16)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
T/M Cal. Off	63	K3890	1220.397		
Inflight Relay On	48	K3890	1330.254		
Reg. Cal. On	46	K3890	1330.343		
Inflight Relays Off	49	K3890	1335.458		
Reg. Cal. Off	47	K3890	1335.547		
T/M Cal. On	62	K3890	1335.637		
T/M Cal. Off	63	K3890	1336.751		
LOX C/D Pump Dump Vlv Clsd	15	K3890	1417.356		

TABLE 5-2 (Sheet 1 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner Start (T_A)*					
T/M Calibration On	62	K3890	-1181.904		
T/M Calibration Off	63	K3890	-1180.784		
RACS Cal (End)		K4802	-1155.942		
T/M Prelaunch C/O Group Off Command		K0403	-1155.338		
T/M Prelaunch C/O Group On Ind - Off		K0408	-1155.299		
T/M Prelaunch C/O Group Off Command - Reset		K0403	-1147.587		
Aft Bus 1 Transfer Internal Indication		K0622	-1147.544		
Aft Bus 2 Transfer Internal Indication		K0623	-1147.278		
Fwd Bus Transfer Internal Indication		K0639	-1147.032		
Ambient Repress Mode Sel Off and Cryo On	37	K3890	-1141.340		
Burner Fuel Prop Vlv Clsd Off	61	K3890	-1141.250		
Burner LOX Shutdown Valve Close Off	75	K3890	-1141.159		
Burner Automatic Cutoff Sys Arm	85	K3890	-1136.550		
Ambient Repress Mod Sel Off and Cryo On	37	K3890	-1131.080	K0195	N/A

$^*T_A$ = 1118:19.000

TABLE 5-2 (Sheet 2 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
S-IVB Ullage Engine No. 1 Off	43	K3890	-1130.923		
S-IVB Ullage Engine No. 2 Off	102	K3890	-1130.826		
Burner Automatic Cutoff Sys Disarm	86	K3890	-1130.735		
Burner Fuel Prop Valve Closed Off	61	K3890	-1130.590		
Burner LOX Shutdown Close Off	75	K3890	-1130.501		
LOX Tank NPV Valve Latch Open On	44	K3890	-1121.404		
Burner Fuel Prop Valve Open On	26	K3890	0.544		
Burner System Rel Rst - Off		K0437	0.551		
Burner LH_2 Prop Valve Cls Off		K0432	0.559	K0180	0.652
Burner LH_2 Prop Valve Opn On		K0431	0.626	K0181	0.652
Burner Exciters On	70	K3890	0.854		
Burner LOX Shutdown Valve Open On	89	K3890	1.275		
Burner LOX Shutdown Valve Close - Off		K0428	1.343		
Burner LOX Shutdown Valve Opn - On		K0427	1.349		

TABLE 5-2 (Sheet 3 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Continuous Vent Valve Closed On	84	K3890	1.483		
LH_2 Tank Continuous Vent Valve Relays Reset - Off		K0452	1.490		
LH_2 Tank Continuous Vent Relief Override Valve Closed - On		K0699	1.510	K0154	1.561
LH_2 Tank Continuous Vent Orf Bypass Valve Open - Off		K0451	1.595		
LH_2 Tank Continuous Vent Orf Bypass Valve Closed - On		K2400	1.596	K0155	1.660
Burner Fuel Prop Valve Open - Off	72	K3890	2.095		
Burner LOX Shutdown Valve Open Off	90	K3890	2.806		
LH_2 Tank Continuous Vent Valve Close Off	87	K3890	3.512		
LH_2 Tank Continuous Vent Valve Relays Reset - On		K0452	3.521		
Burner Exciters Off	71	K3890	4.678		
Burner Sys Rel Rst - On		K0437	4.688		
Burner Automatic Cutoff Sys Arm	85	K3890	7.370		
LH_2 and LOX Repress Sys Rst - Off		K0441	7.374		
Burner Automatic Cutoff Sys Enable On		K0438	7.374		

TABLE 5-2 (Sheet 4 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Repress Control Valve Open On	39	K3890	7.480		
LH_2 Repress Valve Ener - On		K0443	7.488		
LOX Tank Repress Cont Valve Open On	3	K3890	7.688		
LOX Tank Repress Valve Ener On		K0444	7.701		
LOX Tank Repress Cont Valve Open Off	4	K3890	178.027		
LOX Tank Repress Valve Ener Off		K0444	178.039		
Aux Hyd Pump Flt Mode - On	28	K3890	178.853		
Aux Hyd Pump Flt Rel Rst		K0621	178.857		
Aux Hyd Pump On - Ener		K0513	178.940		
LH_2 Tank Repress Valve Ener Off		K0443	181.943		
LOX Tank Repress Cont Valve Open Off	4	K3890	208.286		
LOX Chilldown Pump On	22	K3890	208.446		
LOX Chilldown Pump Rel Rst - Off		K0644	208.453		
LOX Chilldown Pump Inv On		K0519	208.455		
LH_2 Chilldown Pump On	58	K3890	213.502		
LH_2 Chilldown Pump Rel Rst Off		K0641	213.508		

TABLE 5-2 (Sheet 5 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Chilldown Pump Inv On		K0512	213.510		
LH_2 and LOX Prevalve Close Command - On		K0576	218.685		
LH_2 Prevalve Open Indication - Off		K0540	218.786	K0111	218.826
LOX Prevalve Open Indication - Off		K0541	218.807	K0109	218.826
LH_2 Prevalve Closed Indication - On		K0549	219.045	K0112	219.076
LOX Prevalve Closed Indication - On		K0550	219.103	K0110	219.160
Second Burn Relay On	32	K3890	409.372		
LH_2 Tank Flt Press Valve Ener		K0524	409.380		
LH_2 Tank Step Pres Vlv Ener		K0523	409.380		
PU Valve Hardover Position On	17	K3890	409.462		
S-IVB Ull Engine No. 1 On	42	K3890	455.555		
S-IVB Ull Engine Rel Rst		K0429	455.560		
S-IVB Ull Engine No. 2 On	101	K3890	455.645		
LOX Tank Repress Cont Vlv Open Off	4	K3890	455.782		
LH_2 Tank Repress Cont Vlv Open Off	81	K3890	455.920		
Burner Fuel Prop Vlv Closed On	60	K3890	456.066		

TABLE 5-2 (Sheet 6 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner Sys Rel Rst - On		K0437	456.072		
Burner Automatic Cutoff Sys Disarm	86	K3890	456.287		
LH_2 + LOX Repress Sys Rst		K0441	456.292		
Burner Automatic Cutoff Sys Enab		K0438	456.293		
LH_2 Tank Cont Vent Valve Close On	84	K3890	456.481		
LH_2 Tank Cont Vent Valve Rel Rst		K0452	456.487		
Amb Repress Mode Sel On and Cryo Off	36	K3890	456.884		
LH_2 + LOX Repress Sys Rst		K0441	456.887		
LH_2 + LOX Repress Mode Amb		K0440	456.887		
LH_2 Tank Cont Vent Valve Close Off	87	K3890	457.489		
LH_2 Tank Vent Orf + Rlf Rst		K0452	457.498		
Burner Fuel Prop Vlv Clsd Off	61	K3890	458.091		
Burner Sys Rel Rst - On		K0437	458.100		
Burner LOX Shutdown Valve Close On	74	K3890	459.615		
LH_2 Tank Cont Vent Valve Close Off	87	K3890	459.751		

TABLE 5-2 (Sheet 7 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner LOX Shutdown Valve Close Off	75	K3890	460.687		
Burner Sys Rel Rst		K0437	460.695		
LH_2 + LOX Prevlv Close Ener		K0576	518.688		
LOX Prevalve Clsd On		K0550	519.476		
LH_2 Prevalve Clsd On		K0549	519.659		
LOX Prevalves Open - On		K0541	520.833	K0109	520.812
LH_2 Prevalves Open - On		K0540	521.060	K0111	521.062
LH_2 Chilldown Pump Off	59	K3890	528.755		
LH_2 C/D Pmp Inv Off - Indication		K0512	528.760		
LH_2 C/D Pmp Relay Rst Indication		K0641	528.763		
LOX Chilldown Pump Off	23	K3890	528.964		
LOX C/D Pmp Inv Off Indication		K0519	528.970		
LOX C/D Pmp Relay Rst Indication		K0644	528.973		
Aux Hyd Pmp Flt Mode Off	29	K3890	530.240		
Aux Hyd Pump Flt Rel Rst - Off		K0621	530.245		
S-IVB Ull Engine No. 1 Off	43	K3890	530.383		

TABLE 5-2 (Sheet 8 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
S-IVB Ull Engine No. 2 Off	102	K3890	530.472		
S-IVB Ull Engine Rel Rst		K0429	530.481		
PU Valve Hardover Position Off	18	K3890	530.587		
LH_2 Tank Cont Vent Orf Shutoff Valve Open On	111	K3890	548.318		
LH_2 Tank Cont Vent Valve Rel Rst		K0452	548.375		
LH_2 Tank Cont Vent Rlf Ovrrd Shutoff Vlv Open On	107*	K3890	N/A		
LH_2 Cont Vent Orf Bypass Valve Open Indication		K0451	548.431		
LH_2 Tank Cont Vent Rlf Override Valve Closed Off		K0699	548.544		
LH_2 Tank Cont Vent Orf Shutoff Valve Open Off	112	K3890	550.438		
LH_2 Tank Cont Vent Rlf Override Shutoff Valve Open Off	108	K3890	550.527		
LH_2 Tank Cont Vent Valve Rel Rst		K0452	550.535		
LOX Tank Repress Cont Valve Open On	3	K3890	668.087		
LOX Tank Repress Valve Ener		K0444	668.100		

*Buffer saturated and command not recorded; however, talkback (K0699) was recorded.

TABLE 5-2 (Sheet 9 of 9)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Cont Vent Vlv Close On	84	K3890	672.634		
LH_2 Tank Vent Orf + Rlf Rst		K0452	672.641		
LH_2 Tank Vent Rlf Ovrd Cls		K0699	672.660		
LH_2 Tank Vent Orf Bypass Closed		K0451	672.746		
LH_2 Tank Cont Vent Valve Close Off	87	K3890	674.750		
LH_2 Tank Vent Orf + Rlf Rst		K0452	674.758		
LH_2 Tank Repress Cont Valve Open On	39	K3890	688.610		
LH_2 Tank Repress Vlv Ener		K0443	688.619		
LH_2 Tank Step Pres Vlv Ener		K0523	712.170	—	
LH_2 Tank Repress Vlv Ener		K0443	713.574		

SECTION 6

ENGINE SYSTEM

6. ENGINE SYSTEM

The S-IVB stage acceptance firing was performed with an uprated (230,000 lbf thrust) Rocketdyne engine S/N 2122 (figure 6-1) mounted on the stage. The engine was manufactured in the configuration baseline designed for J-2 engine S/N 2088 and subs and described in the Rocketdyne configuration report (R-5788). The manufacturer conducted the engine acceptance test program on 21 and 22 August 1967. The necessary performance demonstration was achieved in two test firings with an accumulated duration of 284.7 sec. As a result of these tests the engine performance tag values were established as follows:

Thrust (F)	226,461 lbf
Engine mixture ratio (EMR)	5.546
Specific impulse (Isp)	423.1 sec

The tag values were established with a LOX flowmeter constant of 5.4790 cycles per gallon (cpg) and an LH2 flowmeter constant of 1.8432 cpg. The gas generator feed system contained orifices with diameters of 0.268 in. for LOX and 0.485 in. for LH2. The engine was equipped with a 1-sec start tank discharge valve timer in the engine control. None of the other modifications significantly affected performance.

6.1 Engine Chilldown and Conditioning

6.1.1 Turbopump Chilldown

Chilldown of the engine LOX and LH2 turbopumps was adequate to provide the conditions required for proper engine start. An analysis of the chilldown operation is presented in paragraphs 7.4 and 8.3.

6.1.2 Thrust Chamber Chilldown

The thrust chamber skin temperature (figure 6-2) was 267 deg R at engine start command, well within the engine start requirements of 235 ±75 deg R. The rate of chilldown, however, was slower than normal, and the terminal temperatures were higher than normal as shown by the comparison of three acceptance firings presented in table 6-1. The LH2 pump start transient buildup characteristics were satisfactory, as shown in figure 6-3.

6.1.3 Engine Start Sphere Chilldown and Loading

Chilldown and loading of the GH2 start sphere (figure 6-4) met requirements for engine start (figure 6-5). The warmup rate averaged 1.66 deg R/min from sphere pressurization to engine start command. Significant data from three S-IVB stages are compared in table 6-2.

6.1.4 Start Tank Refill Performance

Figure 6-6 shows the refill performance of the J-2 start tank during the S-IVB-508 stage acceptance firing. Immediately prior to start tank discharge, the start tank conditions (1,316 psia and 277 deg R) were within the safe start envelope. When the start tank discharge valve (STDV) opened, the GH2 discharged through the turbines as shown in figure 6-6. The discharge was completed and the refill initiated when the temperature and pressure were 196 deg R and 157 psia, respectively, at ESC +1.875 sec. Except for the initial period when the injector was at its lowest temperature (immediately after fuel lead) the refill was practically an exact reversal of the discharge. The tank was topped with lower temperature hydrogen from the LH2 pump discharge starting at ESC +7.25 sec. The topping was terminated when the pressure differential across the topping check valve was lower than the minimum required for flow. At this time (ESC +44.0 sec) the tank pressure and temperature were 1,176 psia and 209.7 deg R, respectively. Environmental heating caused the start tank pressure and temperature to increase to the required level for start.

Figure 6-7 shows the restart capability of the engine based on a Rocketdyne-determined criterion. The start tank pressure at STDV +60 sec (ESC +61.134 sec) was 1,202.5 psia as compared to a minimum allowable of 950 psia. At ESC +57.7 sec , the start tank condition was within the safe start envelope; at engine cutoff command, the pressure and temperature were 1,353.7 psia and 246.4 deg R. The pressure reached the relief valve setting (1,350 psia) during the firing.

6.1.5 Engine Control Sphere Chilldown and Loading

The engine control sphere conditioning was adequate (figure 6-8), and all objectives were satisfactorily accomplished. Significant engine control sphere performance data from four S-IVB stages are compared in table 6-3.

6.2 J-2 Engine Performance Analysis Methods and Instrumentation

Engine performance for the acceptance firing was calculated by use of computer program PA63. The average performance during given intervals was calculated by computer program PA49. Computer program PA53, utilizing revised techniques and the latest Rocketdyne correlations, was used to compute start and cutoff transient performance. Computer program G105-1 was used to determine propellant consumption during burn.* A description of the operation and a comparison of the results of these programs is presented in table 6-4. Data inputs to the computer programs, with the applicable biases, are shown in table 6-5.

6.3 J-2 Engine Performance

The engine performance was satisfactory. Plots of selected data showing engine characteristics are presented in figures 6-9 through 6-13. The engine propellant inlet conditions are discussed in sections 7 and 8.

The 508 acceptance test differed from previous tests in that engine performance was demonstrated for both closed loop and open loop operation. At ESC +350 sec, the PU system was deactivated and the PU valve was commanded to the full open (4.5/1.0 EMR) position. At ESC +410 sec, this command was removed and the valve went to the null position for the remainder of the firing. This test also provided engine performance data at 5.5/1.0, 5.0/1.0, and 4.5/1.0 mixture ratios for use in flight predictions. Cutoff was initiated by the fuel depletion sensors. All engine performance parameters indicated nominal engine performance immediately prior to and during engine cutoff.

*Program UT23 was also used to analyize and study engine component performance.

The engine tag performance level at ESC +60 sec as determined by computer program PA63 (Past-641 deck) was as follows:

Parameter	DAC Acceptance	Rocketdyne Acceptance	Difference	3δ Run to Run
Thrust (lbf)	225,025	226,461	-1436	±2,216
Mixture ratio	5.569	5.546	+0.023	±0.03
Specific impulse (sec)	422.2	423.1	-0.9	±2.46

These values are comparable, within the run-to-run deviations, to the J-2 engine acceptance results. The composite values for steady-state performance are shown in table 6-6.

Flow integral mass analysis indicated that 189,875 lbm of LOX and 37,040 lbm of LH2 were consumed between engine start command and engine cutoff command. The overall stage average performance from the 90 percent performance level (ESC +3.634 sec) to engine cutoff (ESC +459.991 sec) is presented in table 6-6. The variation of specific impulse with mixture ratio is shown in figure 6-14.

The total impulse generated from engine start command to engine cutoff command (fuel depletion) was 96.35 x 10^6 lb sec. This was only slightly less than the predicted total impulse of 96.65 x 10^6 lb sec. The 0.36 percent deviation is within the prediction accuracy of one percent. The 3.202 sec difference between the actual (ESC +459.991 sec) and predicted (ESC +463.193 sec) depletion times is also within the prediction accuracy.

6.3.1 Start Transient

The J-2 engine start transient was satisfactory. A summary of engine performance is presented in the following table:

Parameter	Acceptance Firing	Log Book
Time to 90 percent performance level (seconds)	ESC +3.634	ESC +3.500
Time of start tank discharge command (seconds)	ESC +1.134	ESC +1.000
Thrust at 90 percent performance level (lbf)	169,632	177,968
Total impulse (lbf-sec)	153,780	176,978*

*Based on stabilized thrust at null PU and standard altitude conditions

Thrust buildup to the 90 percent performance level (STDV +2.5 seconds) was within the maximum and minimum thrust bands as shown in figure 6-15. The acceptance firing total impulse was 23,200 lbf-sec lower than the value given in the log book. This was due to a slow thrust rise rate during the second stage travel of the main oxidizer valve. This slow initial thrust buildup was not detrimental to the transient since at STDV +4.0 seconds the acceptance firing thrust was the same as the value shown in the log book at the corresponding time.

6.3.2 Steady-State Performance

The J-2 engine performed satisfactorily during the steady-state portion of engine burn. A performance shift occurred during hardover operation (between ESC +120 and ESC +125 sec). The effect of this shift was observed in the majority of engine instrumentation although no corresponding deviations in PU valve position were noted. The shift, probably caused by a GG bootstrap system resistance shift, resulted in a 0.8 percent thrust variation at the rate of 527 lbf/sec. The allowable is ±500 lbf/sec.

Average performance values for the acceptance firing steady-state operation are presented in figure 6-16 and compared with predicted performance values in table 6-6. During closed PU valve operation, the deviation was less than 0.7 percent. Overall performance deviations were a result of the difference in predicted and actual cutback time (refer to section 11) and the difference in predicted and actual engine response after cutback.

Engine thrust variations during the acceptance firing are presented in table 6-7. They are compared to the predicted acceptance firing thrust history and to Contract End Item (CEI) thrust variation limits for flight. These limits do not apply to acceptance firing performance and are presented for reference only. The thrust variations will be modified by flight effects on stage operation. Thrust variations during four periods of engine operation are presented in figure 6-17 and discussed in the following paragraphs:

a. The thrust variations during hardover, or maximum, engine mixture ratio operation (EMR = 5.5) were within the CEI limits for normal engine operation*. Normal operating thrust

*Engine performance shifts are excluded from CEI specifications.

variations during this period of engine burn are caused by stabilization of the engine and by stage perturbations, including the effects of variations in propellant supply environmental conditions.

b. Thrust variations during the transient period from closed loop PU valve cutback +75 sec to open loop PU valve cutback were within the CEI limits for normal engine operation. The thrust variations during this period were caused by stabilization of the engine after cutback and can be directly linked to movements of the PU valve. Data derived from the acceptance firing will aid in the flight calibration of the PU system in order to more accurately predict the thrust variation during this cutback transient.

c. Thrust variations were also examined during the periods of 4.5/1.0 EMR and 5.0/1.0 EMR open loop operation. Since the PU valve was in a fixed position during these intervals the thrust variations during these times were compared to the required limits during full closed PU valve operation. These variations were also within CEI limits.

6.3.3 Cutoff Transient

The time lapse between engine cutoff, as received at the J-2 engine, and thrust decrease to 11,500 lbf was within the maximum allowable time of 800 ms for the acceptance firing as shown in the following table:

Parameter	Acceptance Firing	Log Book
Time of thrust decrease to 11,500 lbf (ms)	499	339
Measured total impulse (lbf-sec)	36,615*	34,105
Total impulse corrected to null (-2.0 deg) PU valve position (lbf-sec)	37,223	34,105
Total impulse corrected to 0 deg F oxidizer valve skin temperature (lbf-sec)	**	35,185

*PU valve at -1.29 deg

**Valve skin temperature data not available

The thrust decay time for the acceptance firing was greater than the log book value, and the cutoff total impulse was correspondingly higher than the log book value. For this firing, the total impulse was corrected to null PU valve position so that a direct comparison could be made to the log book value. It was not possible to accurately correct to 0 deg F LOX valve skin temperature since the measurement was not available; however, this correction would be approximately -4,500 lb-sec for an acceptance

test since the MOV temperature should be about 355 deg R. Based on this assumption, the corrected total impulse would be within 2,500 lbf-sec of the log book value. Figure 6-18 presents the data for the thrust chamber pressure cutoff transient, the accumulated cutoff impulse, and the cutoff thrust to the 11,500 lbf level.

6.4 Engine Sequencing

The engine sequencing was satisfactory throughout the acceptance firing and compatible with the engine logic and the acceptance firing test plan. However, as in past acceptance tests, the sequence times differ in many respects from the values quoted in the log book.

Most of the disagreements between measured and log book values are insignificant and may be ascribed to sampling rate errors or to the effects of the liquids that are present during the acceptance firing but absent during log book testing. Almost all event times were obtained from the hardwire because the sampling rate was better than for TM.

Figure 6-19 presents the engine start sequence for the acceptance firing; table 6-8 presents the time of significant events during the firing and compares them with the nominal values.

6.5 Component Operation

6.5.1 Main LOX Valve

The main LOX valve opened satisfactorily during the acceptance firing. The opening time data are as follows:

Item	Ambient Dry Specification	Acceptance Firing
First stage travel (ms)	50 ±25	55
First plateau (ms)	510 ±70	516
Second stage travel (ms)	1,825 ±75	1,917
Total time (ms)	2,385 ±170	2,488

The above valve opening times were within specifications for the acceptance test. The valve closing time was 187 ms which is approximately 52 ms longer than the ambient specifications; however, this did not contribute to any significant reduction in cutoff transient performance. This closure time was in the range established by the previous acceptance firings.

6.5.2 PU Valve

At engine start command, the PU valve was at -1.84 deg (null) which was within the -2 ±2 deg limit. PU activation occurred at ESC +6.166 sec. The PU valve went to the high EMR position where it remained until PU cutback at ESC +196 sec as shown in figure 6-12. The engine mixture ratio (EMR) was properly controlled to the required reference of 5.0/1.0 following cutback.

Also the PU valve went to the full open position when commanded to do so during the open loop portion of the test. When the full open command was removed the valve returned to near null position.

However the PU valve operation was not entirely satisfactory. The valve motion was irregular, and the valve appeared to be binding during closed loop cutback and active PU control (figure 6-13). Also when the full open command was removed the valve returned to -1.3 deg (approximately 0.5 deg from its prestart null position).

Following the test the PU valve was removed and tested per ECP 666. The valve failed the test. Approximately 30 volts were required to move the valve instead of the nominal 15 volts. As a result of this test, the PU valve was replaced.

6.5.3 LH2 Pump

Pump performance was normal throughout the test. The stall margin as indicated by the characteristic head versus flow curve in figure 6-3 was normal. The pump also performed satisfactorily during mainstage and responded characteristically to PU system cutback and excursions. Mainstage pressure and speed data are presented in figure 6-10.

6.5.4 LOX Pump

LOX pump performance was satisfactory. LOX pump speed and discharge pressure and temperature responded to PU system cutback and excursions and also to engine inlet conditions. The pressure and temperature increases across the pump were satisfactory. Performance profiles indicative of the pump operation are shown in figure 6-10.

6.5.5 Turbines

Performance of both LH2 and LOX turbines was satisfactory. Temperatures and pressures for both turbines responded as expected to PU system cutback and excursions. Pressure and temperature drops across the turbines were nominal. Performance profiles are presented in figure 6-10.

6.5.6 Gas Generator

The gas generator (GG) performance was adequate. The GG chamber pressure and LH2 turbine inlet temperature indicated nominal values before and after EMR cutback. The performance shift discussed in paragraph 6.3.2 was also apparent in the GG chamber pressure data and was probably caused by changes in the LOX bootstrap line resistance. Plots of GG performance are shown in figures 6-10 and 6-20.

6.5.7 Engine-Driven Hydraulic Pump

The engine-driven hydraulic pump performed satisfactorily during the acceptance firing. The required horsepower at 60 sec after engine start was 5.36.

6.6 Engine Vibration

There were five vibration measurements monitored on the engine during the firing. Three were located on the chamber dome, one at the LOX turbopump and one at the LH2 turbopump. The data from these measurements are shown in figures 6-21 and 6-22. The vibration amplitudes were in agreement to those measured during past acceptance firings.

TABLE 6-1

THRUST CHAMBER CHILLDOWN DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N	S-IVB-505N
Thrust chamber chilldown initiated (sec from simulated liftoff)	-407.938	-407.942	-408.537	-405.356
Thrust chamber chilldown terminated (sec from simulated liftoff)	488.793	488.808	488.474	488.288
Thrust chamber temperature				
Required at engine start command (deg R)	235 ±75	235 ±75	235 ±75	260 ±50
At engine start command (deg R)	267	221	237	247
At end of chilldown (deg R)	255	213	228	244

TABLE 6-2

ENGINE START SPHERE PERFORMANCE DATA

Parameter	Temperature (°R)			Pressure (psia)			Mass (lbm)		
	508	507	506N	508	507	506N	508	507	506N
Engine start requirement	See start region Figure 6-5			See start region Figure 6-5			--	--	--
Engine start command							3.53	3.50	3.42
After start sphere blowdown	196	188	194	157	185	132	0.63	0.77	0.54
Engine cutoff command	246	233	247	1,354	1,329	1,325	4.09	4.22	3.97
Total GH2 usage during start	--	--	--	--	--	--	2.90	2.73	2.88

TABLE 6-3

ENGINE CONTROL SPHERE PERFORMANCE DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N	S-IVB-505N
Temperature				
Required at engine start command (deg R)	N/A	277 ±30	287 ±20	291 ±20
At engine start command (deg R)	292	290	298	297
At engine cutoff command (deg R)	273	246	252	262
Pressure				
Required at engine start command (psia)	2,800 to 3,450	2,800 to 3,450	2,800 to 3,450	2,975 ±475
At engine start command (psia)	3,048	2,974	2,933*	3,082
At engine cutoff command (psia)	2,825	1,922	1,987*	2,161
Mass				
At engine start command (lbm)	**	1.88	1.81	1.89
After engine cutoff command (lbm)	**	1.46	1.43	1.54
Total helium usage (lbm)	**	0.42	0.38	0.35

N/A Not applicable

* Pressures are lower than usual because of low GSE regulator setting.

** Engine control sphere helium mass at any time is insignificant because it is tied into the LOX and LH2 tank ambient repressurization spheres.

TABLE 6-4

COMPARISON OF COMPUTER PROGRAM RESULTS

PROGRAM	INPUT	METHOD	RESULTS (at ESC +60 sec)
G105 Mode 3	LOX and LH_2 flowmeters, pump discharge pressures and temperatures, chamber pressures, chamber thrust area	This program is used only for propellant consumption. Flowrates are computed from flowmeter data and propellant densities. Mass consumptions are obtained by integrating the flowrates.	W_T = 537.1 lbm/sec W_{LOX} = 455.3 lbm/sec W_{LH_2} = 81.8 lbm/sec
PA53	Thrust chamber pressure, chamber throat area	The C_F is computed from equation $C_F = f(P_c)$ and thrust is computed from equation $F = C_F A_t P_c$. The impulse is determined from integrated thrust.	Refer to paragraph 6.3.3.
PA63	Pump inlet and outlet conditions, PU valve position, chamber pressure, turbine inlet and outlet conditions, flowmeter speed	Math models of rocket engine components are linked together by program which iterates among the component models until an operating point is reached where the power required by the pumps "balances" the power available from the turbines.	F = 226,892 lbf $\dot{W}_T$ = 537.6 lbm/sec I_{sp} = 422.0 MR = 5.57

TABLE 6-5 (Sheet 1 of 2)

DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
Chamber Press	G-105 PA63 PA53	D0001	Close agreement between (H/W) and (T/M)	-10.0	-15 psi bias for P_c purge effect +5 psi bias to obtain rated ISP
LH_2 Pump Discharge Press	G-105-1 PA63	D0008 (T/M)	Close agreement between (H/W) and (T/M)	0	
LH_2 Pump Discharge Temperature	G-105-1 PA63	C0134 (T/M)	Close agreement between (H/W) and (T/M)	0	
LOX Pump Discharge Pressure	G-105-1 PA63	D0009 (T/M)	Close agreement between (H/W) and (T/M)	0	
LOX Pump Discharge Temperature	G-105-1 PA63	C0133 (T/M)	Close agreement between (H/W) and (T/M)	0	
LOX Flowrate	G-105-1 PA63	F0001 (T/M)	Close agreement between (H/W) and (T/M)	-2.04 gpm	Agree with actual pip count
LH_2 Flowrate	G-105-1 PA63	F0002 (T/M)	Close agreement between (H/W) and (T/M)	-62.79 gpm	Agree with actual pip count
LH_2 Pump Inlet Pressure	PA63	D0002 (T/M)	Close agreement between (H/W) and (T/M)	+0.2 psi	Compare to ullage pressure prior to flow
LH_2 Pump Inlet Temperature	PA63	C0003 (T/M)	Close agreement between (H/W) and (T/M)	+0.2 psi	Agree with saturation temperature prior to flow

TABLE 6-5 (Sheet 2 of 2)

DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
LOX Pump Inlet Pressure	PA63	D0003	Close agreement between (H/W) and (T/M)	-0.4 psi	Compare to ullage pressure prior to flow
LOX Pump Inlet Temperature	PA63	C0004 (T/M)	Close agreement between (H/W) and (T/M)	0	
PU Valve Position	PA63	G0010 (T/M)	Close agreement between (H/W) and (T/M)	0	

TABLE 6-6 (Sheet 1 of 2)

ENGINE PERFORMANCE

PARAMETER	CLOSED PU VALVE OPERATION			REFERENCE MIXTURE RATIO OPERATION			OVERALL PERFORMANCE 90% TO ECC		
	ACTUAL	PREDICTED	% DEV	ACTUAL	PREDICTED	% DEV	ACTUAL	PREDICTED	% DEV
Thrust (lbf)	227,037	228,004	0.4	200,545	203,248	1.3	210,793	210,092	-0.3
Total Flowrate (lbm/sec)	535.68	538.93	0.7	470.38	477.23	1.5	495.63	494.64	-0.2
LOX Flowrate (lbm/sec)	453.44	456.52	0.7	391.12	397.57	1.6	415.41	414.49	-0.2
LH_2 Flowrate (lbm/sec)	82.24	82.41	0.2	79.27	79.66	0.5	80.23	80.15	-0.1
Engine Mixture Ratio	5.514	5.539	0.5	4.934	4.991	1.1	5.165	5.158	-0.1
Specific Impulse	423.83	423.06	-0.2	426.34	425.89	-0.1	425.44	424.93	-0.1

TABLE 6-6 (Sheet 2 of 2)

ENGINE PERFORMANCE

PARAMETER	OPEN PU VALVE OPERATION (OPEN-LOOP PU)			NULL PU VALVE OPERATION (OPEN-LOOP PU)		
	ACTUAL	PREDICTED	% DEV	ACTUAL	PREDICTED	% DEV
Thrust (lbf)	170,864	171,508	0.4	199,536	200,504	0.5
Total Flowrate (lbm/sec)	397.41	400.25	0.7	469.37	470.96	0.3
LOX Flowrate (lbm/sec)	322.40	325.48	0.9	391.18	392.27	0.3
LH_2 Flowrate (lbm/sec)	75.01	74.77	-0.3	78.13	78.70	0.7
Engine Mixture Ratio	4.298	4.353	1.3	5.003	4.985	-0.4
Specific Impulse (sec)	429.95	428.50	-0.3	425.12	425.73	0.1

TABLE 6-7

ENGINE THRUST VARIATIONS

Parameter	Limits	Time Period: Hardover Operation (5.5/1.0 EMR)	Time Period: Transient From PU Vlv Cutback (Closed Loop) +75 Sec to PU Cutback (Open Loop)	Time Period: Hardunder Operation (4.5/1.0 EMR)	Time Period: Null Operation (5.0/1.0 EMR)
Variation in Mean Thrust Level (Predicted Minus Actual) (lbf)	Allowable	±4000	±8000	±4000	±4000
	Actual	+1063	+1685	+650	+905
	Predicted	——	——	——	——
Oscillations About Mean Thrust Level (lbf)	Allowable	±2500	±7500	±2500	±2500
	Actual	±868	±2165	±665	±625
	Predicted	±650	±1400	±150	±250
Rate of Change of Thrust (lbf/sec)	Allowable	±500	±500	±500	±500
	Actual	-182	+460	+103	+94
	Predicted	±100	±100	±100	±100
Thrust Acceleration (lbf/sec/sec)	Allowable	±125	±500	±125	±125
	Actual	+48	-152	+25	-6
	Predicted	——	——	——	——

TABLE 6-8 (Sheet 1 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0021 (K0021)	*Engine Start Command P/U			0	0	
		K0007 (K0531)	Helium Control Solenoid Enrg P/U	Within 10 ms of K0021	002	002
		K0010 (K0454)	Thrust Chamber Spark on P/U	Within 10 ms of K0021	001	001
		K0011 (K0455)	Gas Generator Spark on P/U	Within 10 ms of K0021	001	001
		K0006 (K0535)	Ignition Phase Control Solenoid Enrg P/U	Within 20 ms of K0021	001	001
		K0012 (K0530)	Engine Ready D/O	Within 20 ms of K0006	004	003
		K0126 (K0558)	LOX Bleed Valve Closed P/U	Within 200 ms of K0007	150	148
		K0127 (K0557)	LH2 Bleed Valve Closed P/U	Within 200 ms of K0007	117	115
		K0020 (K0627)	ASI LOX Valve Open P/U	Within 20 ms of K0006	065	064

(K0XXX) Actual number from acceptance firing event recorder.

*Engine ready and stage separation signals (or simulation) are required before this command will be executed.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 2 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0119 (G506)	Main Fuel Valve Closed D/O	60 ±30 ms from K0006	049	050
		K0118 (G506)	Main Fuel Valve Open P/U	110 ±60 ms from K0119	161	112
K0008 (K0537)	*Ignition Detected			Within 250 ms of K0021 P/U	273	273
K0021 (K0021)	**Engine Start D/O			Approx 200 ms from K0021 P/U	1338	1338
K0096 (K0536)	***Start Tank Disc Control Solenoid Enrg			1,000 ±50 ms from K0021 P/U	1134	1134
		K0123 (G508)	Start Tank Disc Valve Closed D/O	100 ±20 ms from K0096	1247	113
		K0122 (G508)	Start Tank Disc Valve Open P/U	105 ±20 ms from K0123	1354	107
K0005 (K0538)	Mainstage Control Solenoid Enrg			450 ±30 ms from K0096	1586	452

*This signal must be received within 1,110 ±60 ms of K0021 P/U or cutoff will be inititated.

**This signal drops out after a time sufficient to lockin the engine electrical.

***An indication of fuel injection temperature of -150 ±40 deg F (or simulation) is required before this command will be executed. This command also actuates a 450 ±30 ms timer which controls the start of mainstage.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 3 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0096 (K0536)	Start Tank Disc Control Solenoid Enrg D/O	450 $\pm$30 ms from K0096	1586	452
		K0121 (G507)	Main LOX Valve Closed D/O	50 $\pm$20 ms from K0005	1629	043
		K0116 (G509)	Gas Generator Valve Closed D/O	140 $\pm$10 ms from K0005	1685	099
		K0122 (G508)	Start Tank Disc Valve Open D/O	95 $\pm$20 ms from K0096	1704	118
		K0117 (G509)	Gas Generator Valve Open P/U	50 $\pm$30 ms from K0116	1814	129
		K0124 (G510)	LOX Turbine Bypass Valve Open D/O		1789	
			LOX Turbine Bypass Valve 80% Closed	400 $^{+150}_{-50}$ ms from K0122	2035	331
		K0123 (G508)	Start Tank Disc Valve Closed P/U	250 $\pm$40 ms from K0122	1962	258
		K0125 (G510)	*LOX Turbine Bypass Valve Closed P/U		2101	
K0158 (K0572)	Mainstage Press Switch #1 Depress D/O				3222	

*Within 5,000 ms of K0005 (Normally = 500 ms)

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 4 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0159	Mainstage Press Switch #2 Depress D/O				3256	
K0191 (K0610)	*Mainstage OK				3221	
		K0120 (G507)	Main LOX Valve Open P/U	2,435 ±145 ms from K0005	4117	2488
		K0010 (K0454)	Thrust Chamber Spark on D/O	3,300 ±200 ms from K0005 P/U	4887	3301
		K0011 (K0455)	Gas Generator Spark On D/O	3,300 ±200 ms from K0005 P/U	4887	3301
K0507 CSS-22	PU Activate Switch P/U				6166	

*One of these signals must be received within 4,410 ±260 ms from K0021 P/U, or cutoff will be initiated. Signal occurs when LOX injection pressure is 500 ±30 psig.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 5 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
K0013 (K0522)	Engine Cutoff PU (New time reference)			0	0	0
		K0005 (K0538)	Mainstage Control Solenoid Enrg D/O	Within 10 ms of K0013	0	0
		K0006 (K0535)	Ignition Phase Control Solenoid Enrg D/O	Within 10 ms of K0013	-002	-002
		K0020 (K0622)	ASI LOX Valve Open D/O		016	
		K0120 (G507)	Main Oxidizer Valve Open D/O	50 $\pm$15 ms from K0005	061	061
		K0117 (G509)	Gas Generator Valve Open D/O	75 $^{+25}_{-35}$ ms from K0006	007	009
		K0118 (G506)	Main Fuel Valve Open D/O	90 $\pm$25 ms from K0006	078	080
		K0121 (G507)	Main Oxidizer Valve Closed P/U	120 $\pm$15 ms from K0120	248	187
		K0116 (G509)	Gas Generator Valve Closed P/U	500 ms from K0006	219	221
		K0119 (G506)	Main Fuel Valve Closed P/U	225 $\pm$25 ms from K0118	338	260

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 6 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
K0158 (K0572)	*Mainstage Press Switch A Depress P/U				181	
K0159 (K0573)	Mainstage Press Switch B Depress P/U			*	176	
K0191 (K0610)	Mainstage OK D/O			*	182	
K0007 (K0531)	Helium Control Solenoid Enrg D/O			1,000 ±110 ms from K0013	990	990
SS-22 K0507	PU Activate Switch D/O			N/A		
		K0125 (G510)	Oxidizer Turbine Bypass Valve Closed D/O		270	
		K0124 (G510)	Oxidizer Turbine Bypass Valve Open P/U	10,000 ms from K0005	719	719
K0126 (K0558)	LOX Bleed Valve Closed D/O			30,000 ms from K0005	4368	4368
K0127 (K0557)	LH2 Bleed Valve Closed D/O			30,000 ms from K0005	8219	8219

*Signal drops out when pressure reaches 425 ±25 psig.

P/U - Pickup

D/O - Dropout

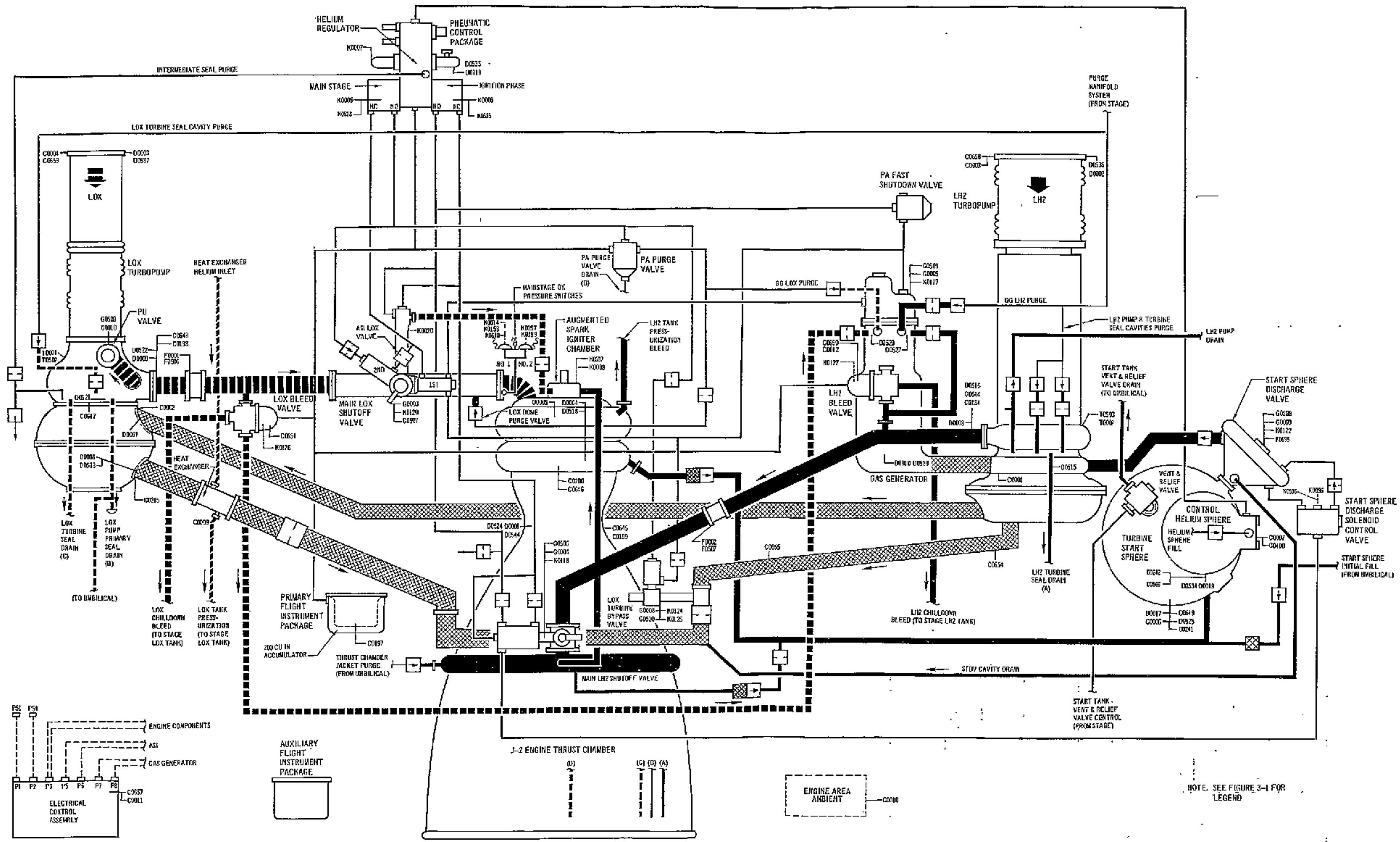


Figure 6-1. J-2 Engine System and Instrumentation

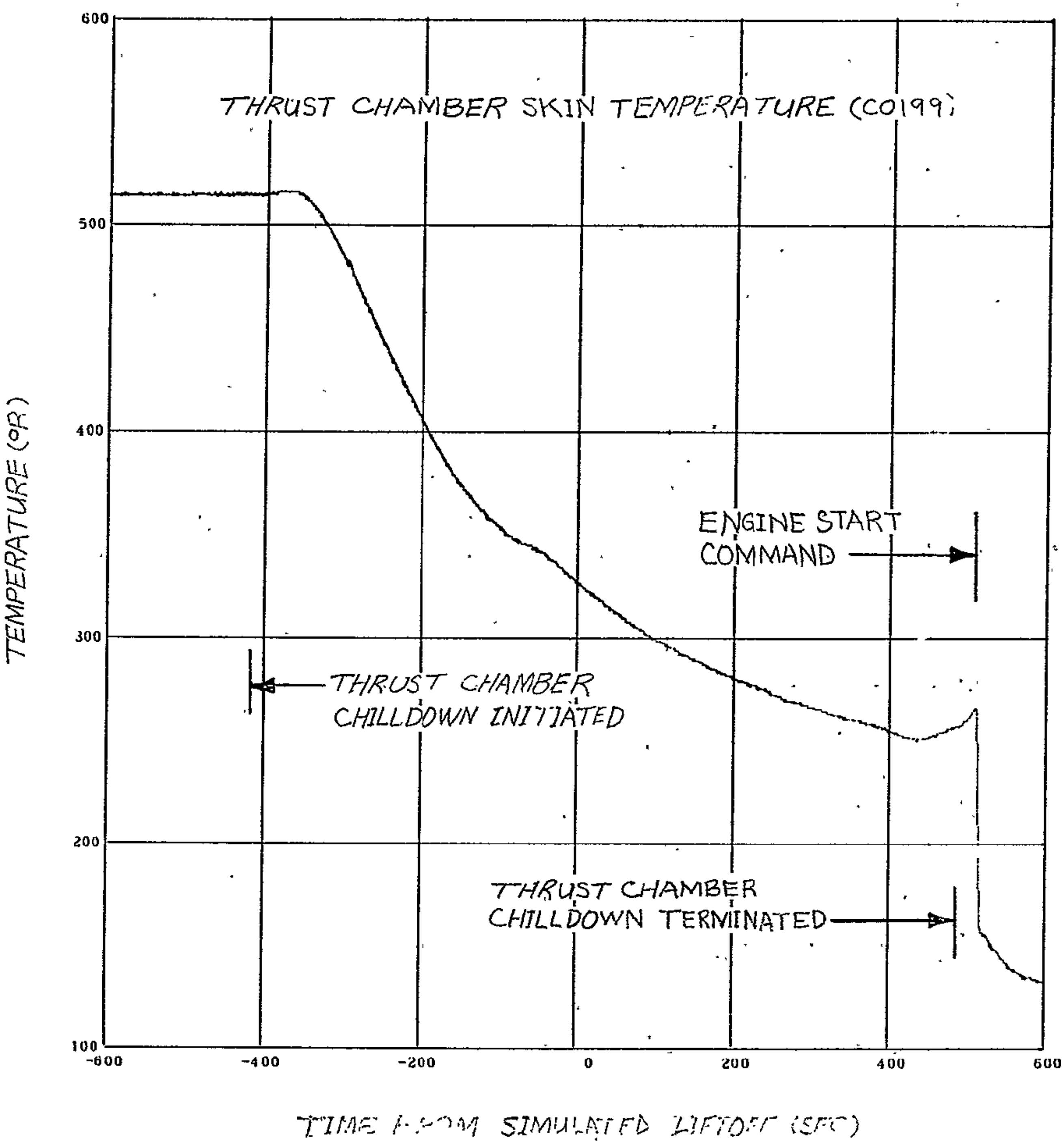


FIGURE 6-2. THRUST CHAMBER CHILLDOWN

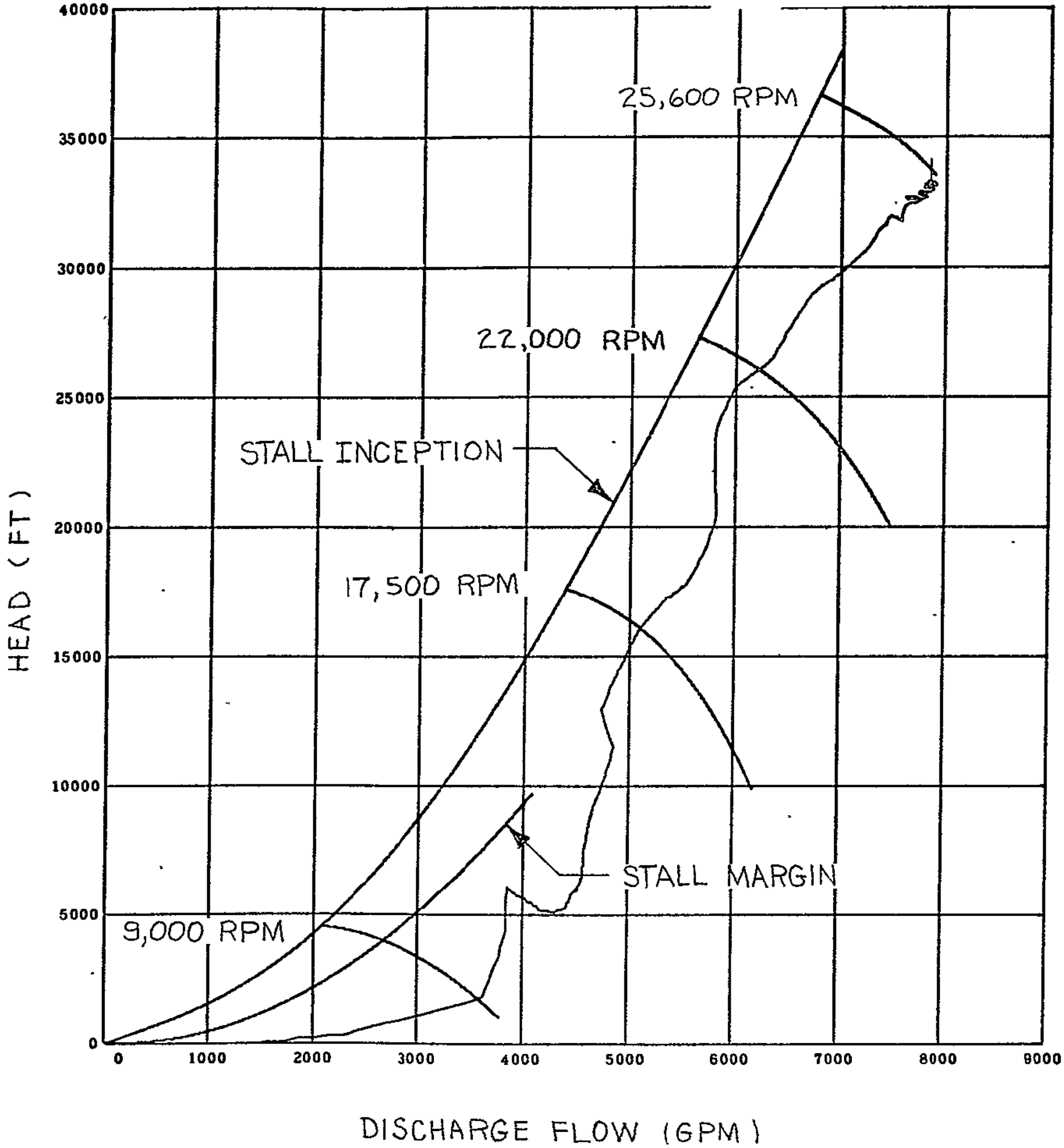


FIGURE 6-3. LH2 PUMP PERFORMANCE DURING ENGINE START

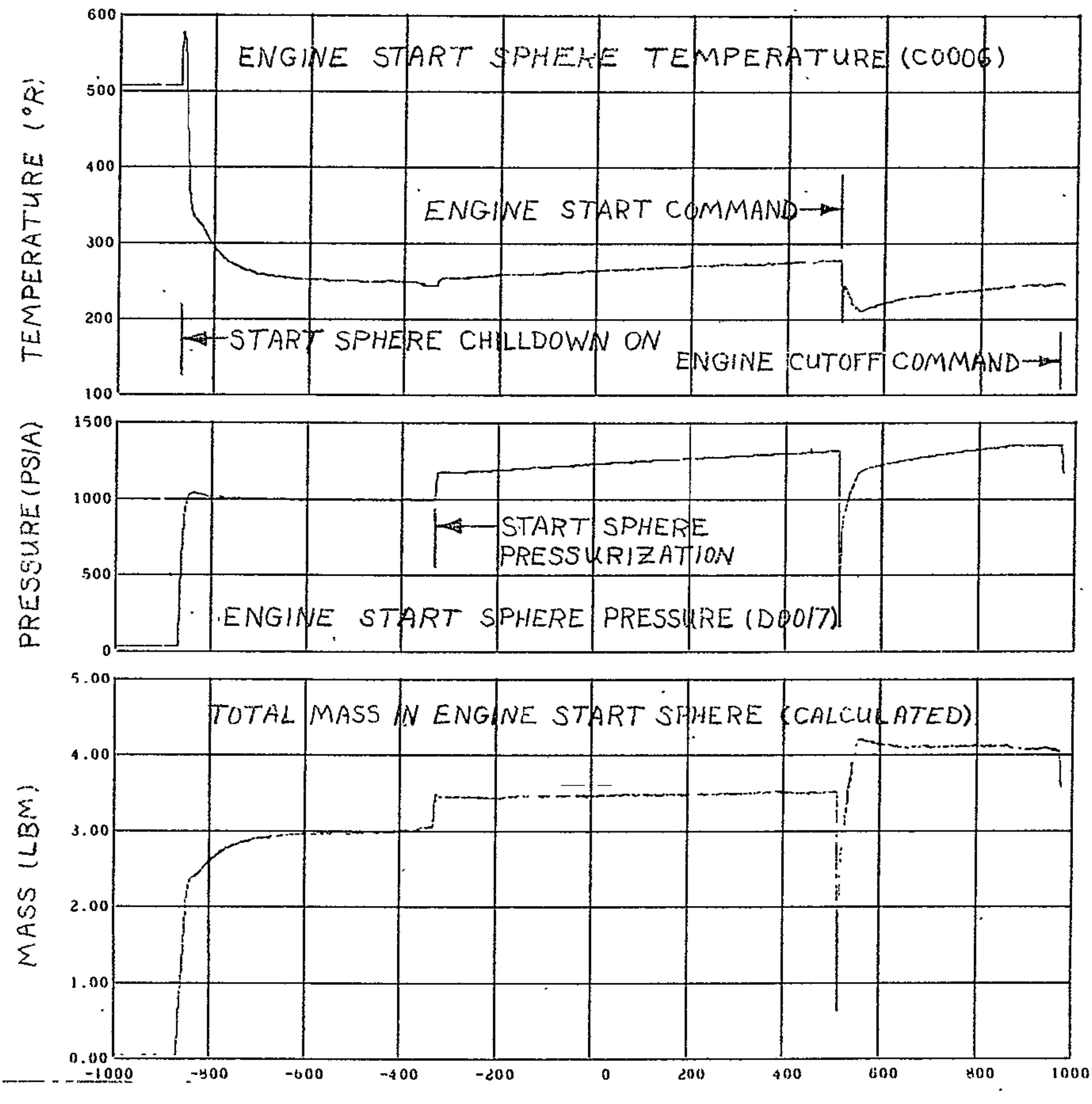


FIGURE 6-4. ENGINE START SPHERE PERFORMANCE

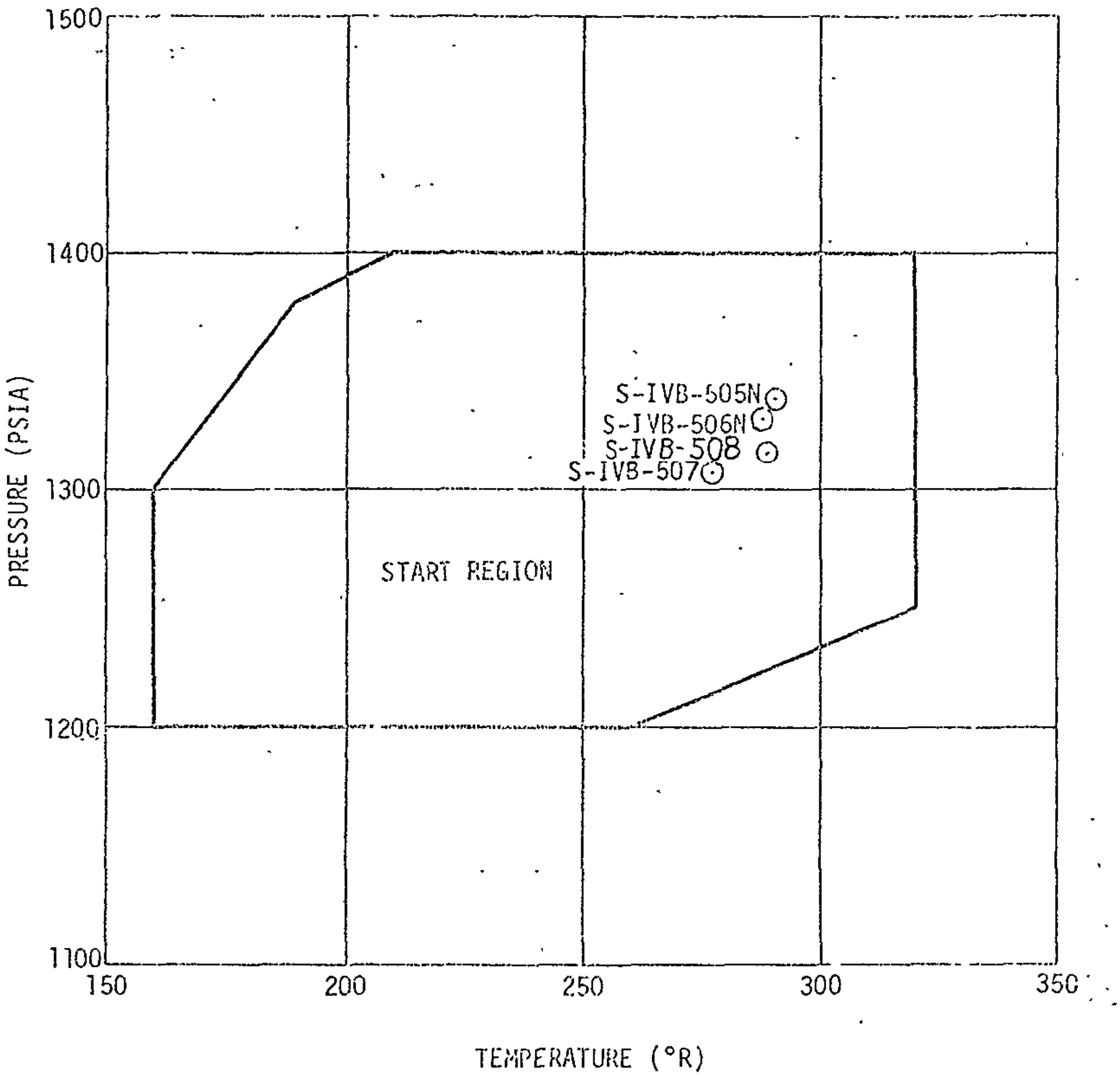


Figure 6-5. Engine Start Sphere START REGION

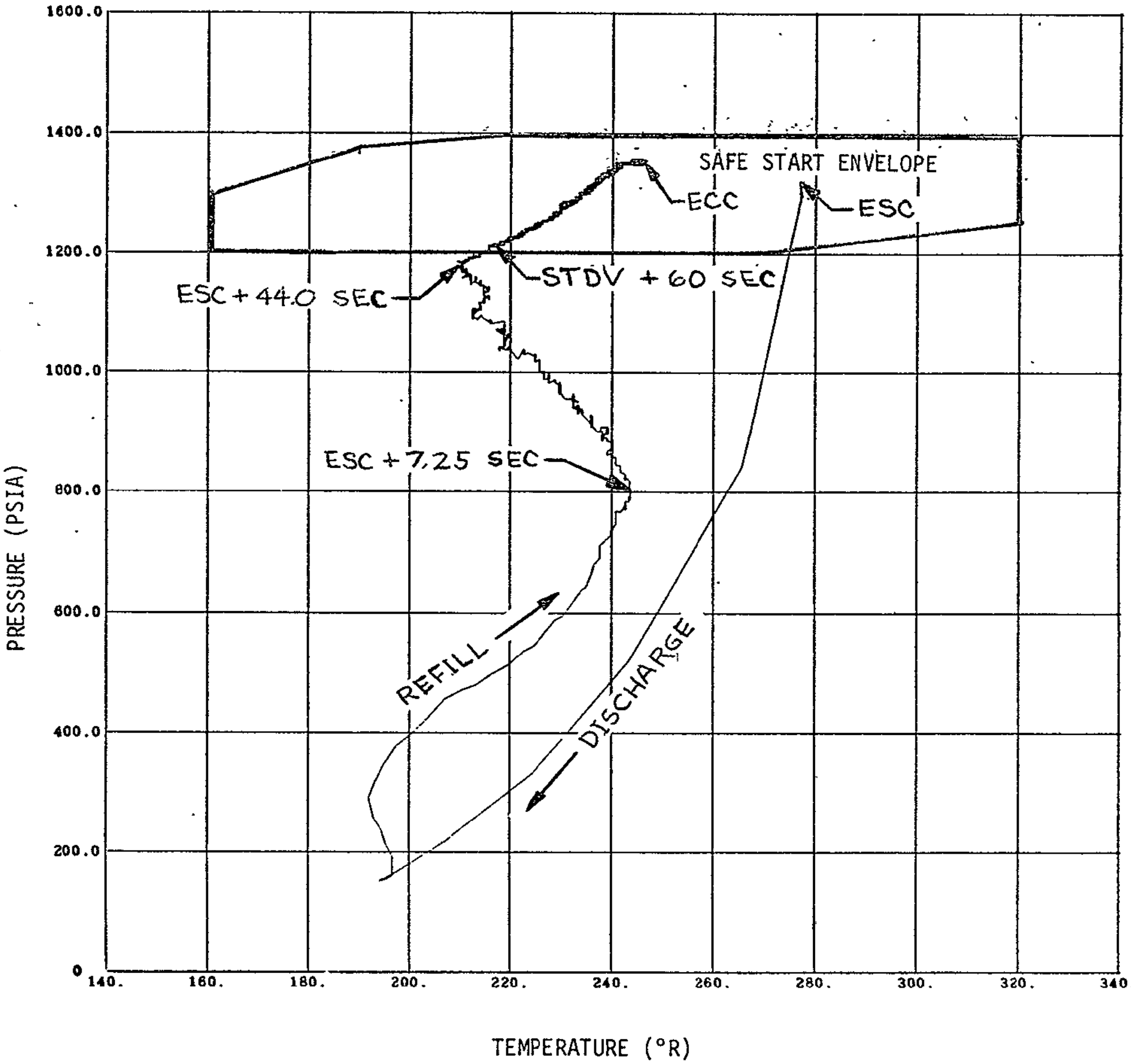
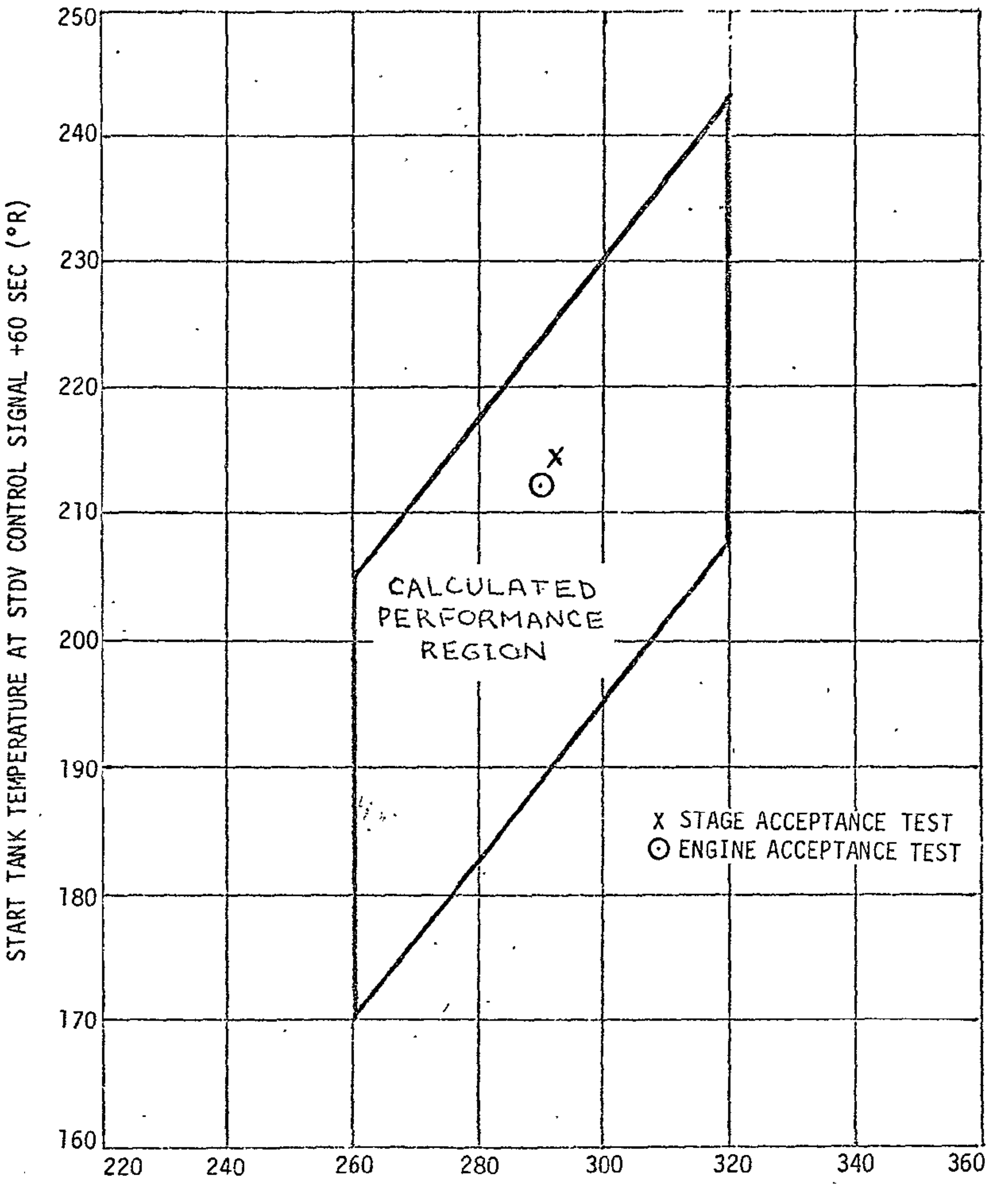


Figure 6-6. Start Tank Refill Performance



*CORRECTED TO ZERO DIFFERENTIAL WITH RESPECT TO HELIUM TANK TEMPERATURE

Figure 6-7. S-IVB-503 Restart Capability

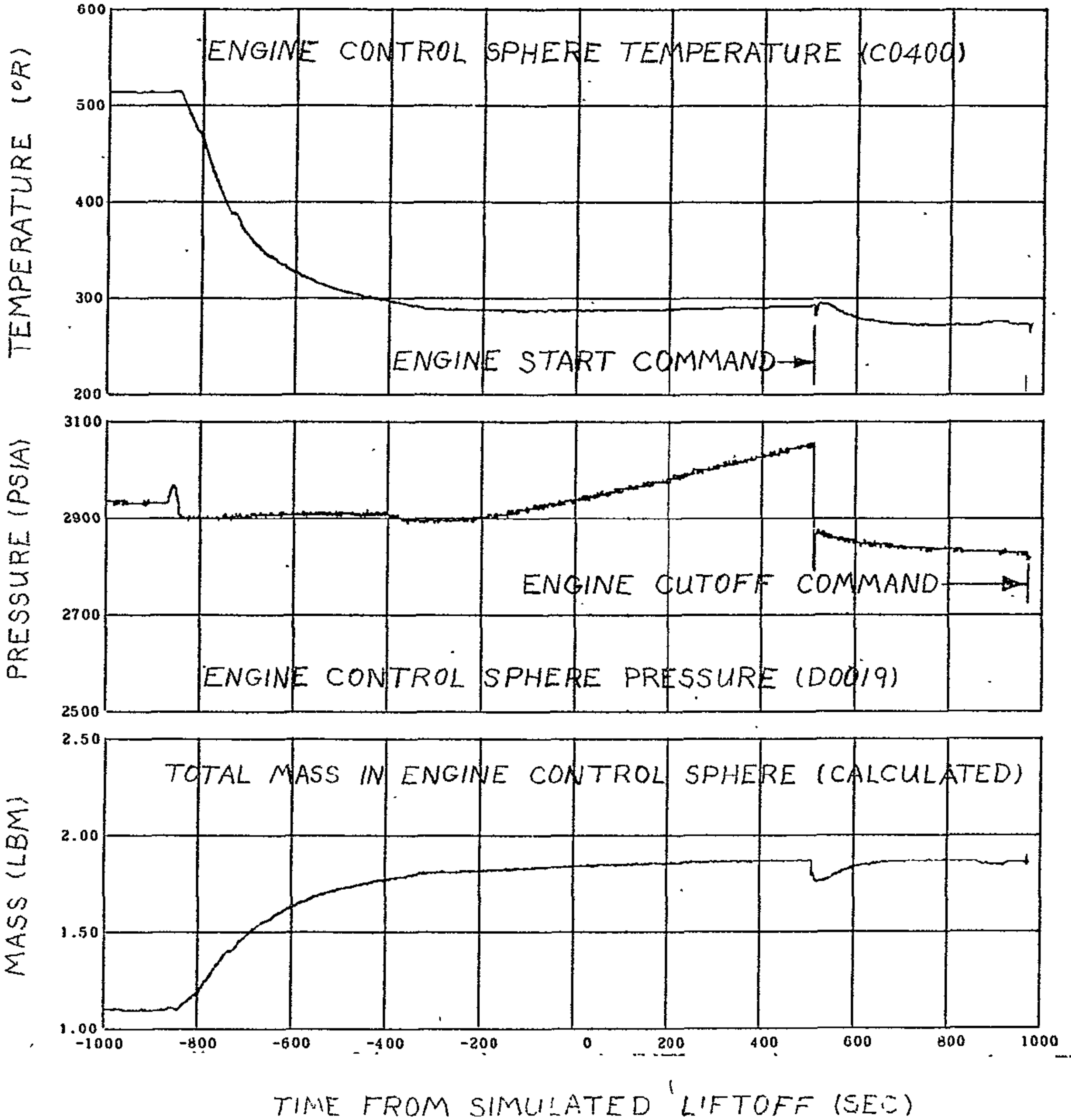


FIGURE 6-8. ENGINE CONTROL SPHERE PERFORMANCE

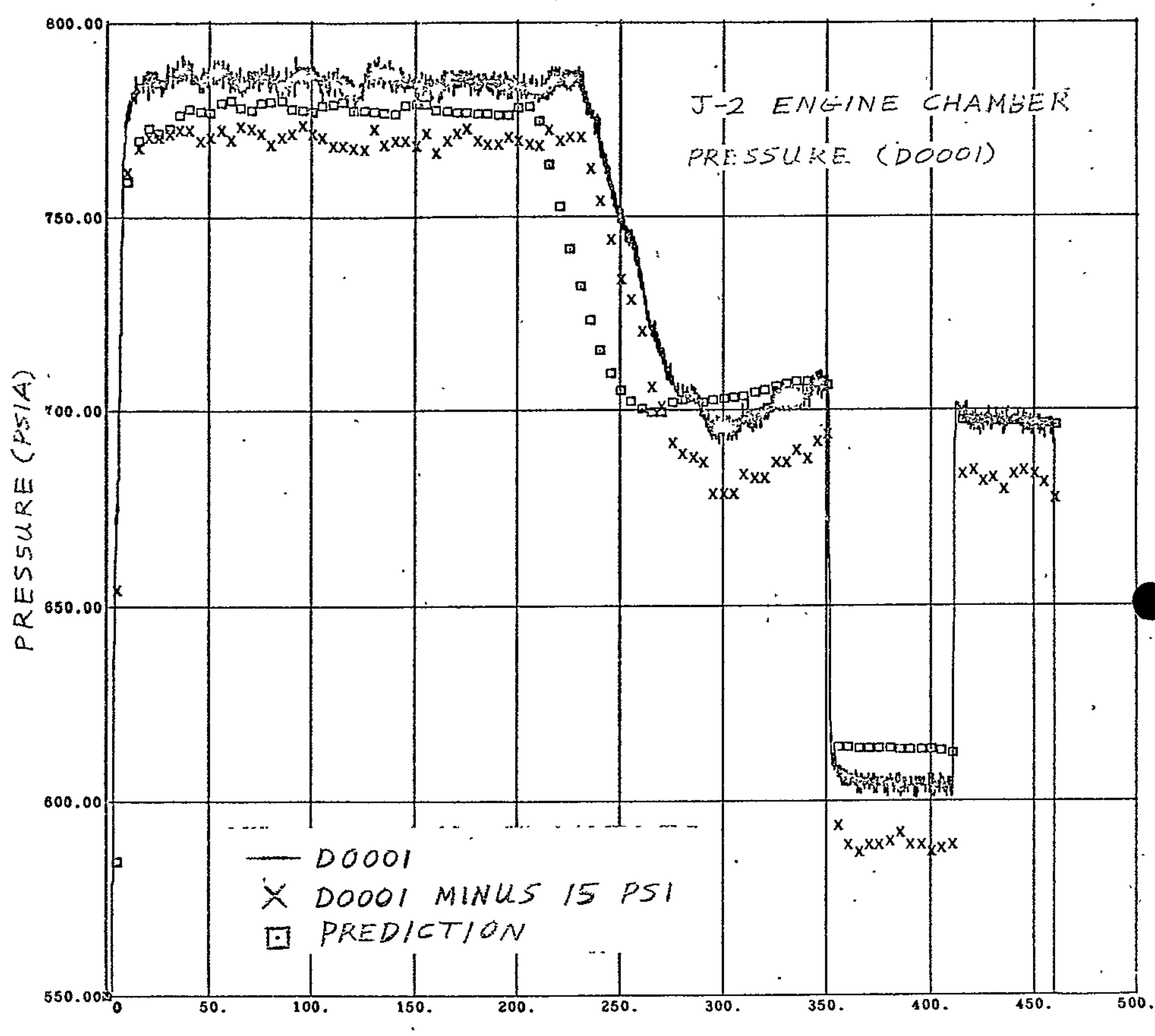


FIGURE 6-9. J-2 ENGINE CHAMBER PRESSURE

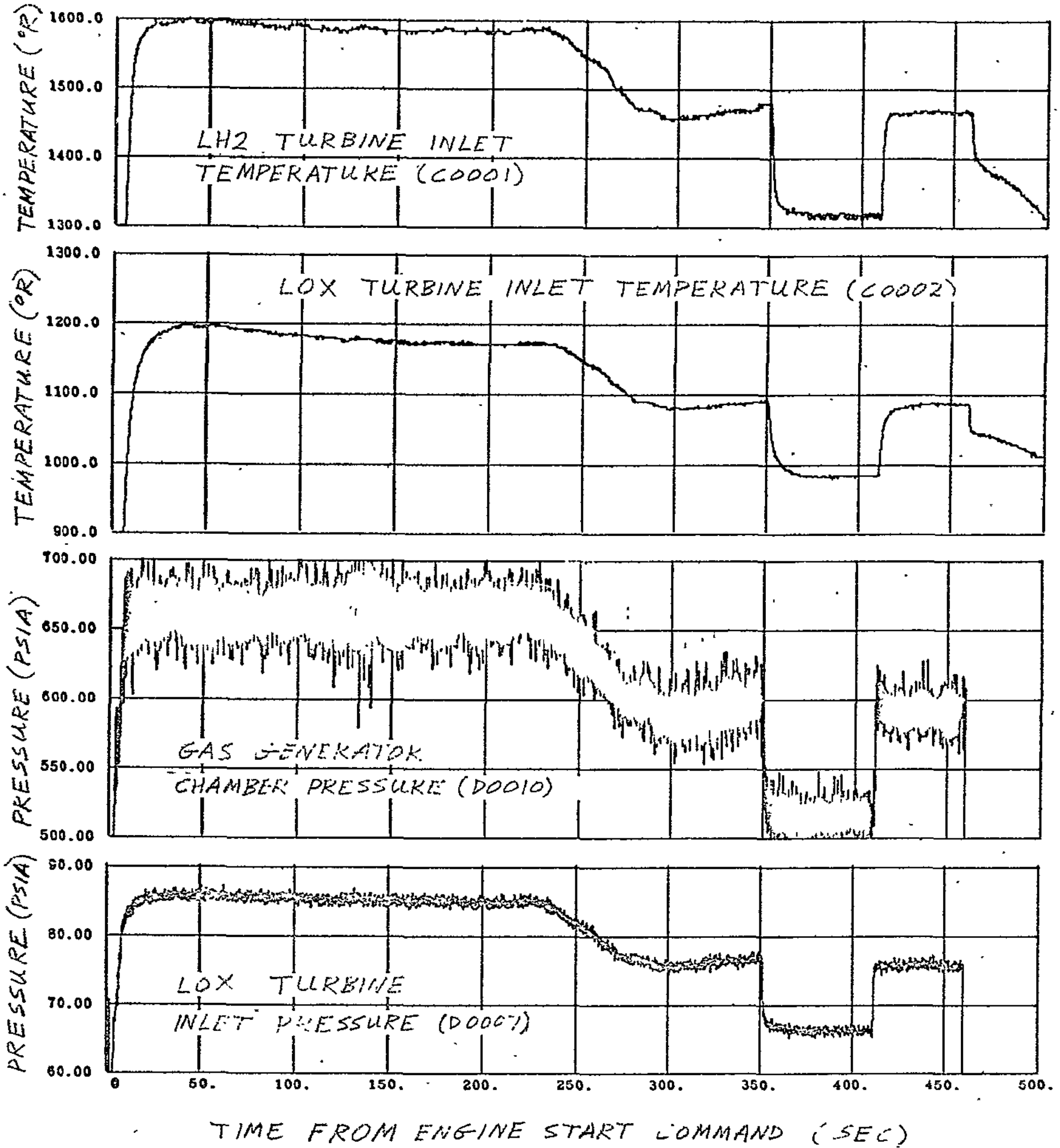


FIGURE 6-10. TURBOPUMP OPERATING CHARACTERISTICS (SHEET 1 OF 2)

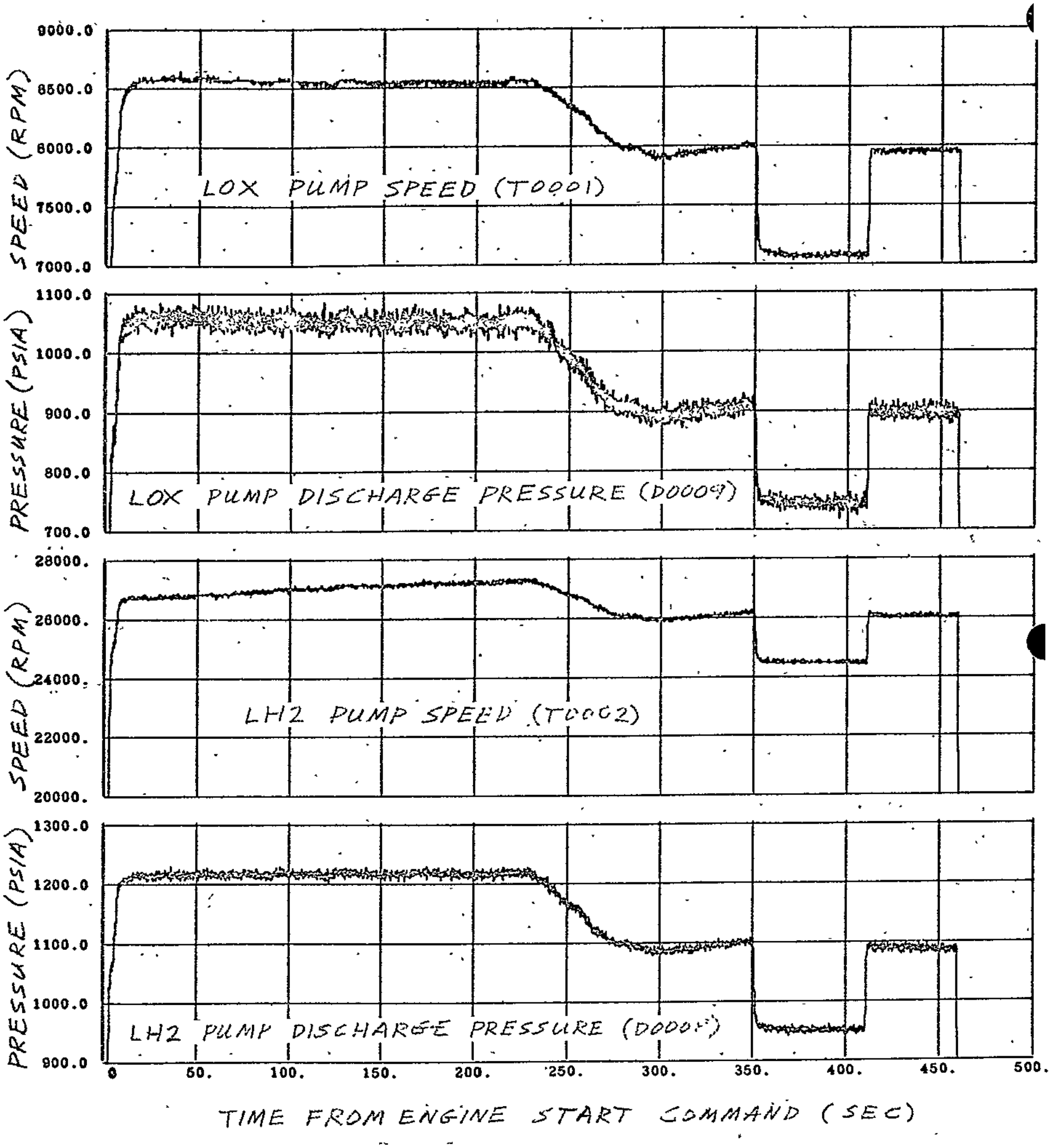


FIGURE 6-10. TURBOPUMP OPERATING CHARACTERISTICS (SHEET 2 OF 2).

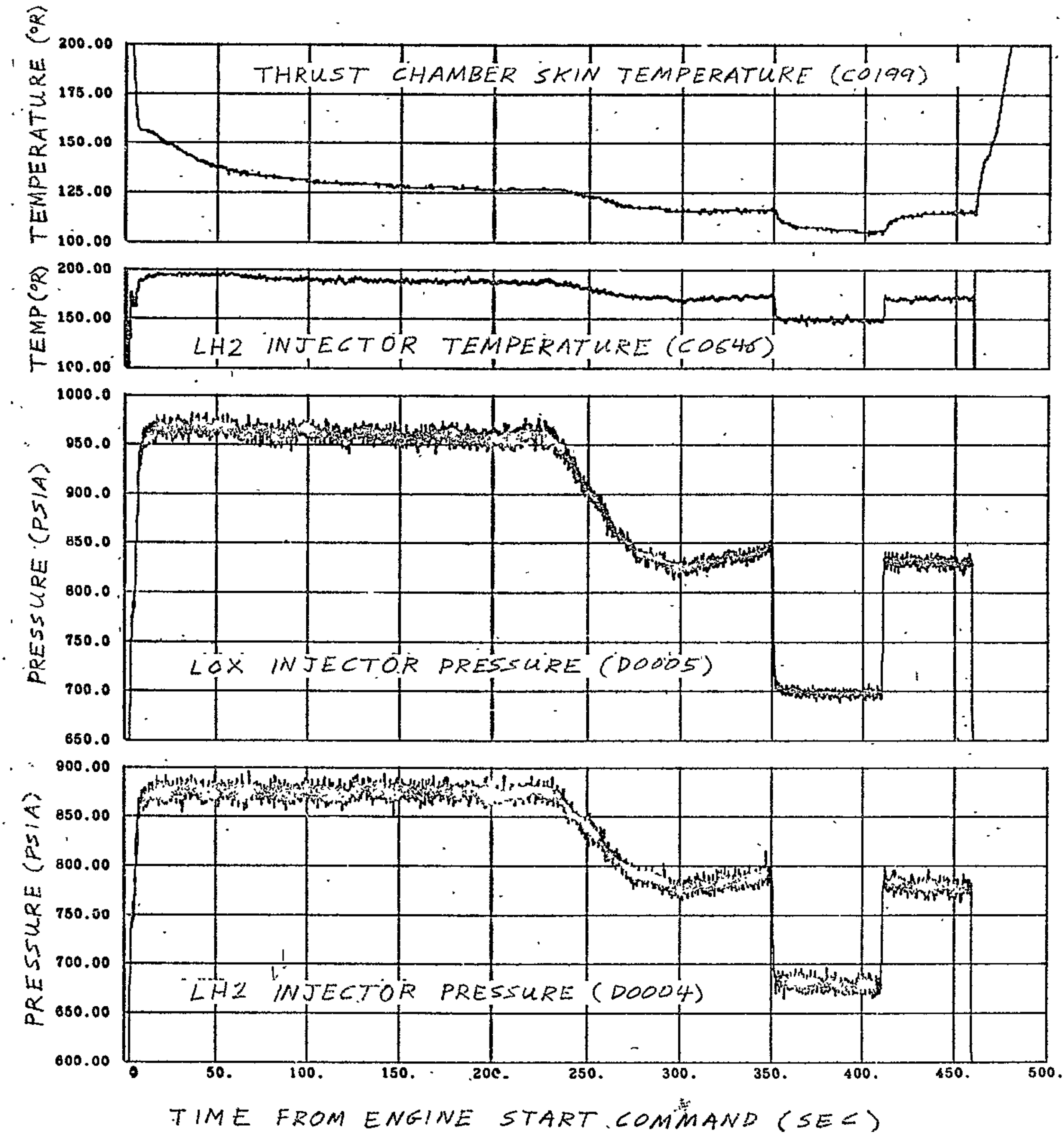


FIGURE 6-11. J-2 ENGINE INJECTOR SUPPLY CONDITIONS

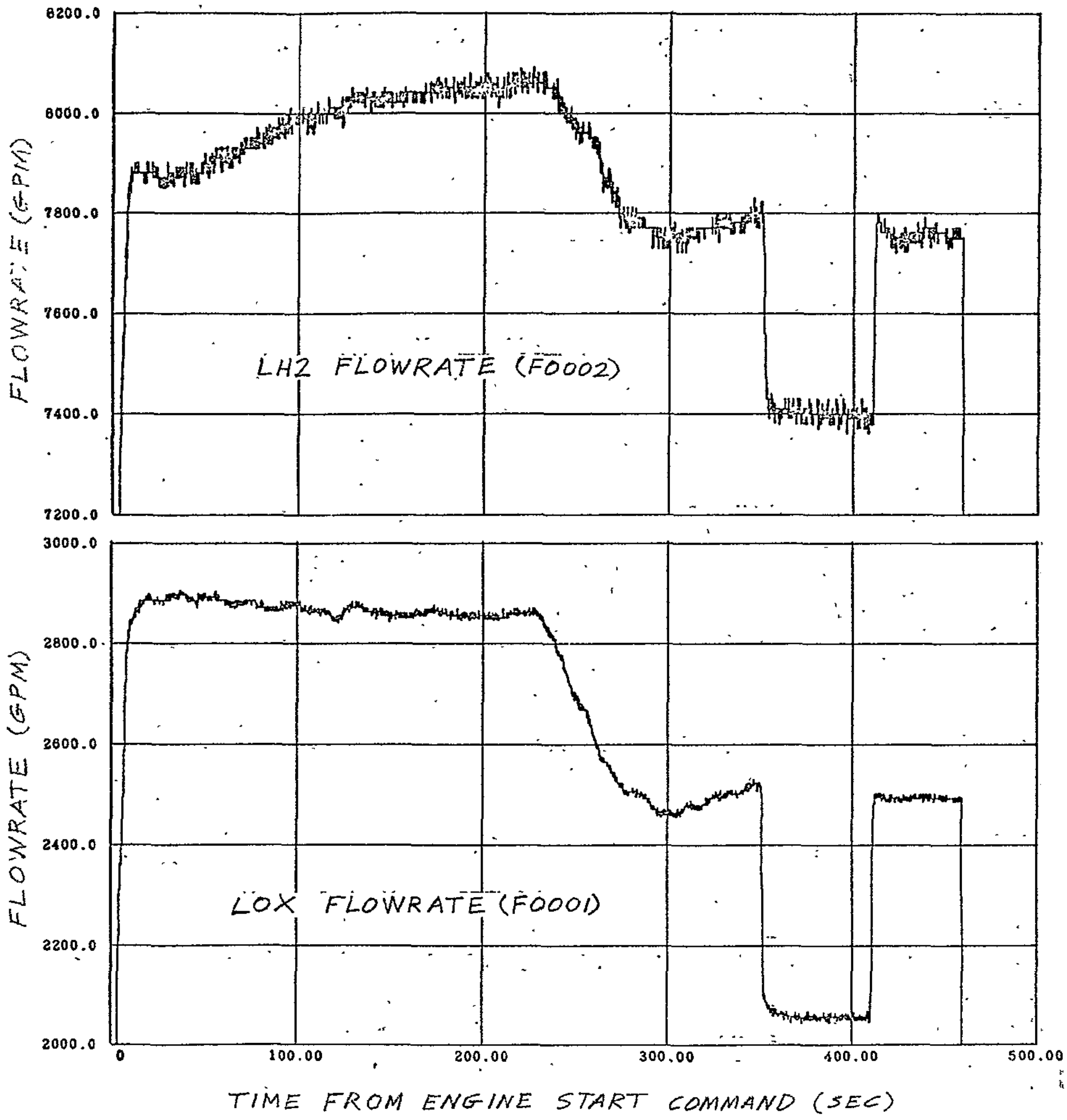


FIGURE 6-12. LOX AND LH2 FLOWRATE

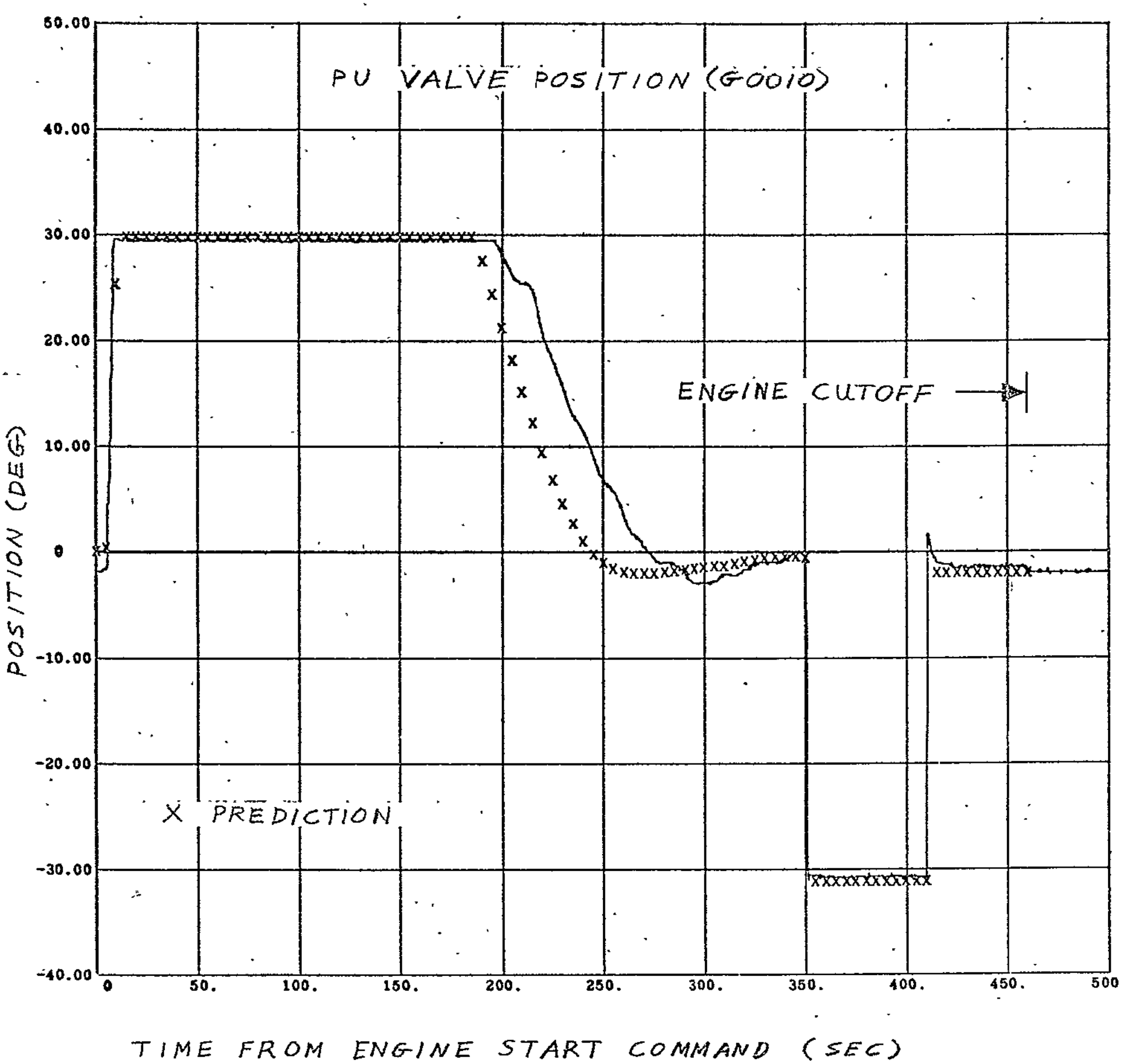


FIGURE 6-13. PU VALVE POSITION

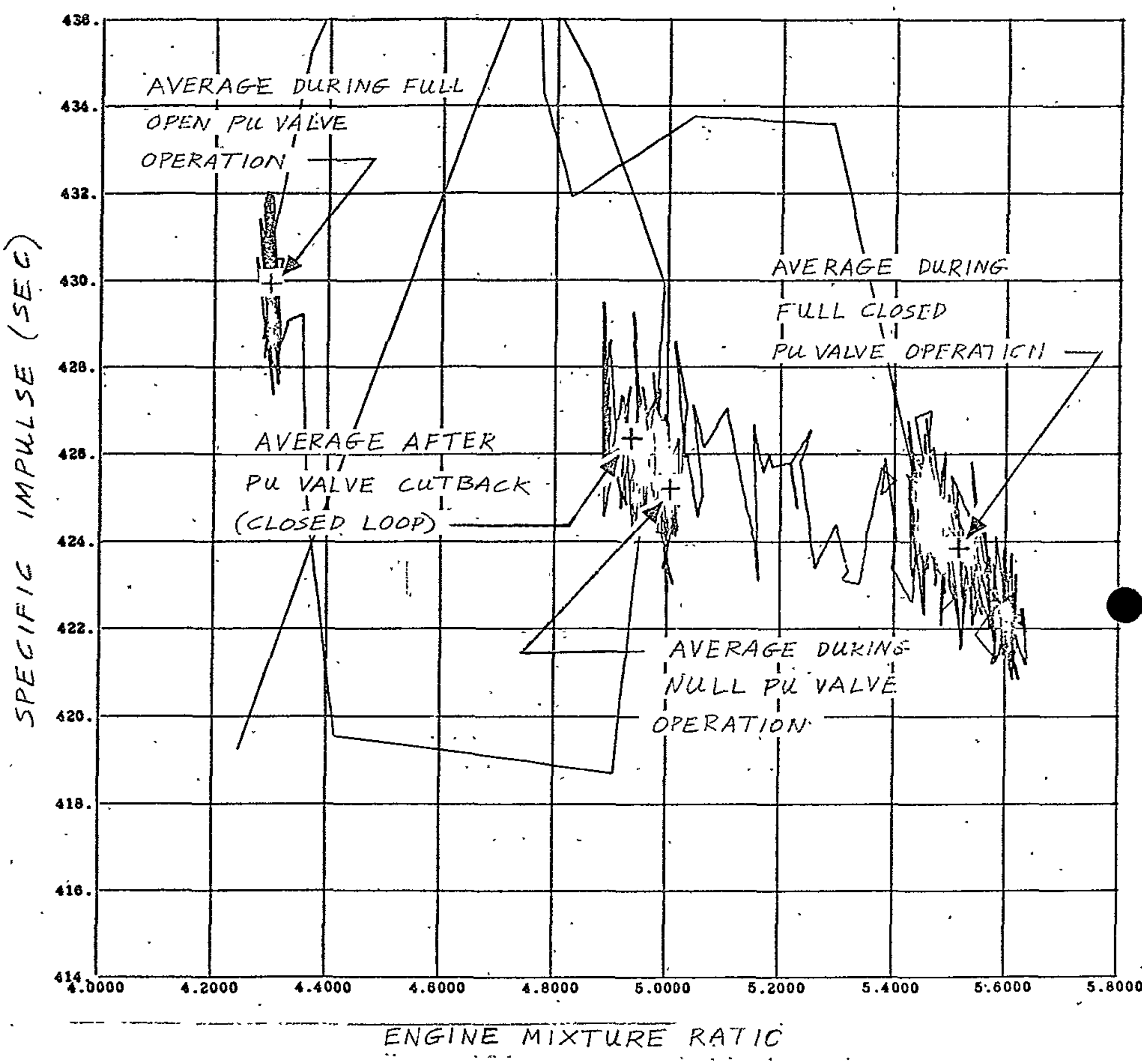


FIGURE 6-14. ENGINE MIXTURE RATIO VS. SPECIFIC IMPULSE

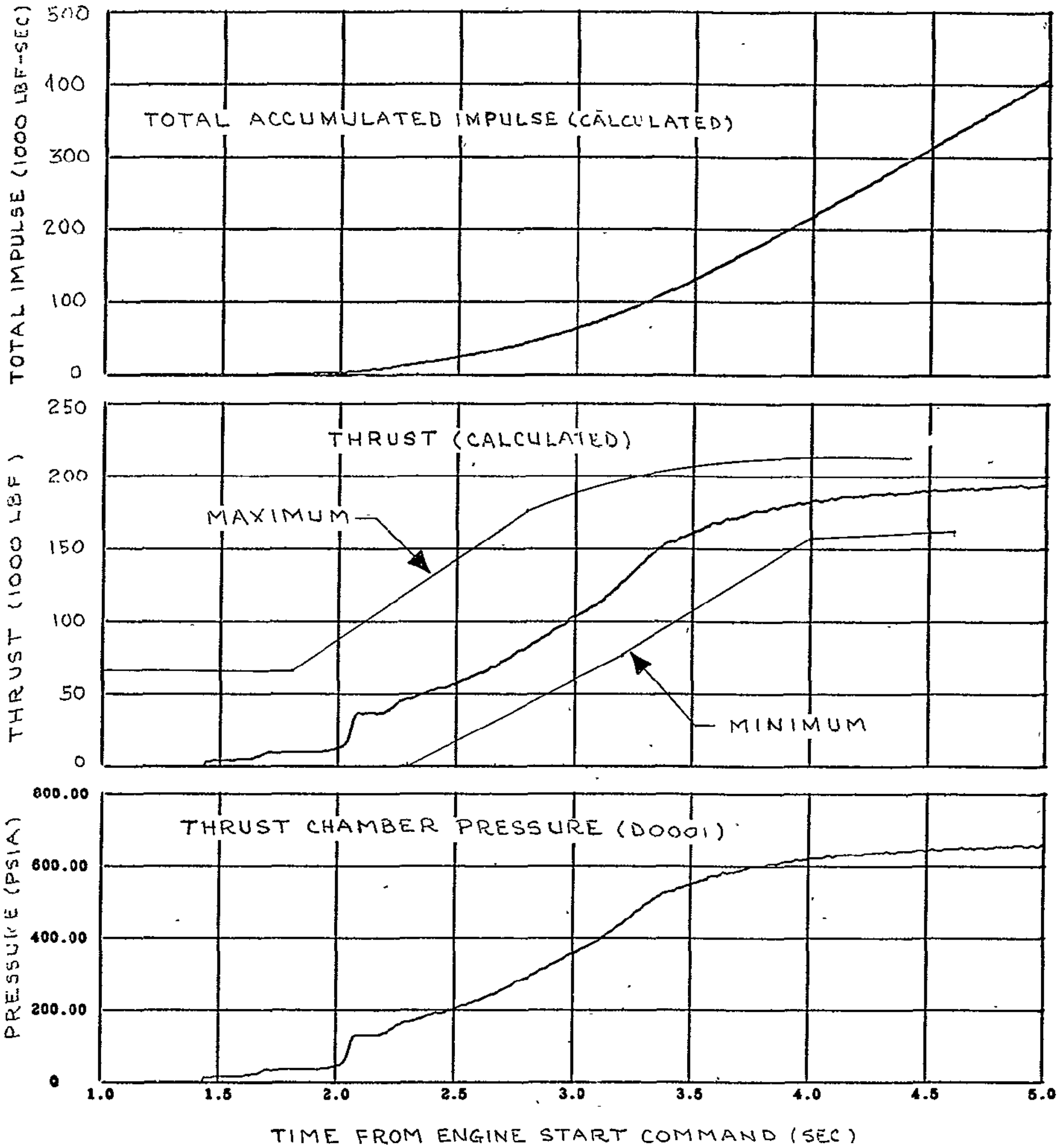


FIGURE 6-15. ENGINE START TRANSIENT CHARACTERISTICS

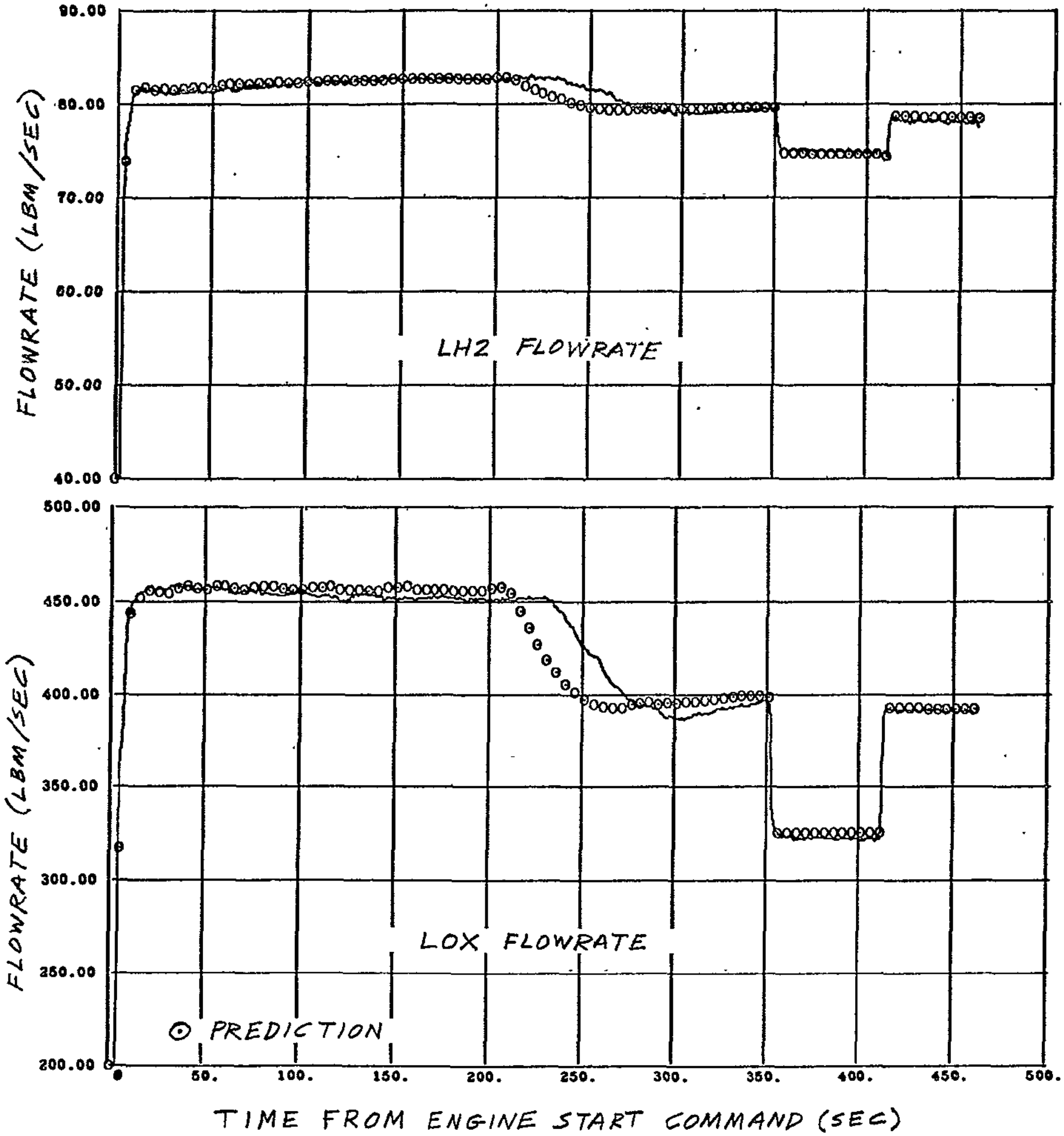


FIGURE 6-16. ENGINE STEADY-STATE PERFORMANCE (SHEET 1 OF 3)

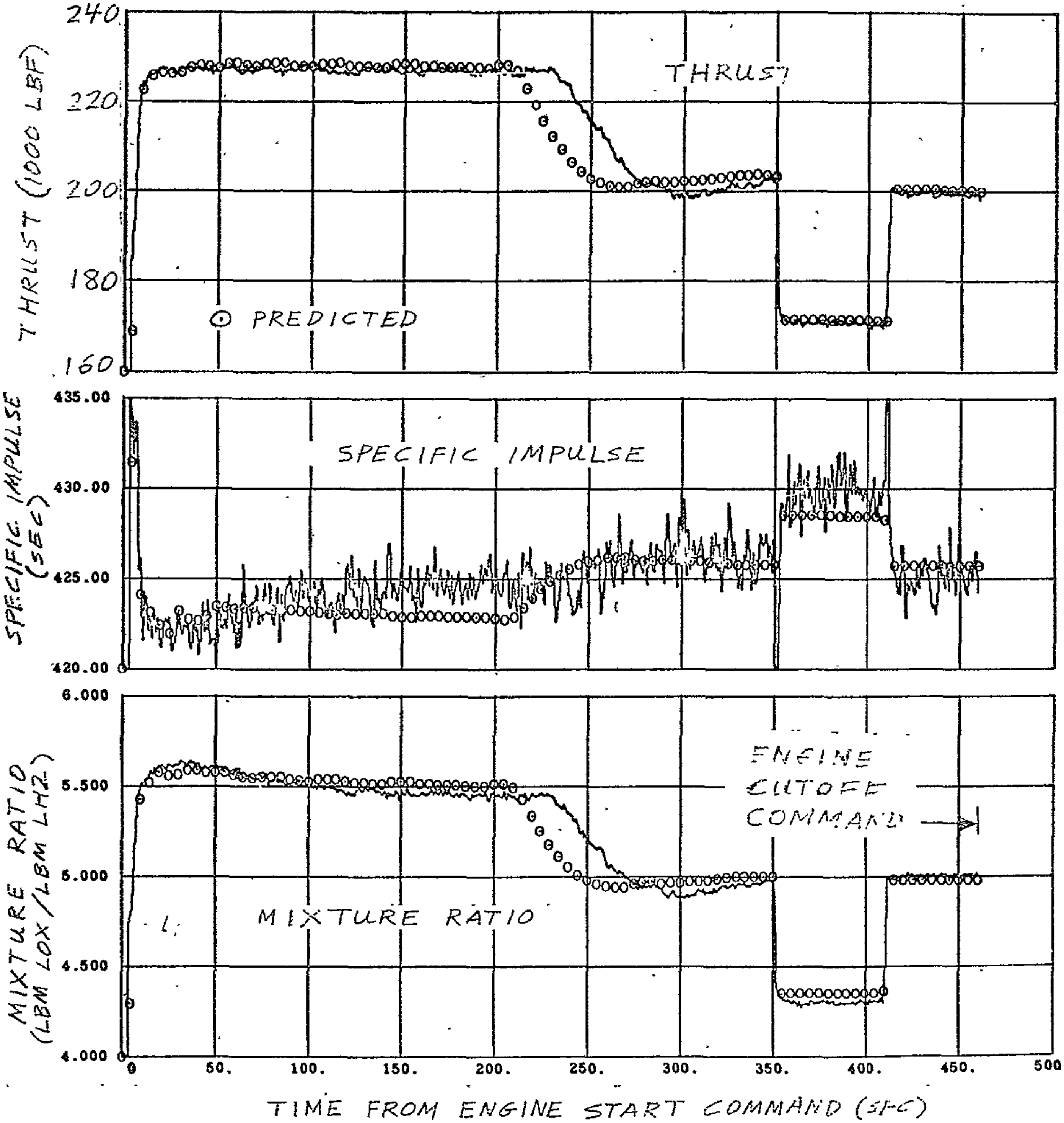


FIGURE 6-16. ENGINE STEADY STATE PERFORMANCE (SHEET 2 OF 3)

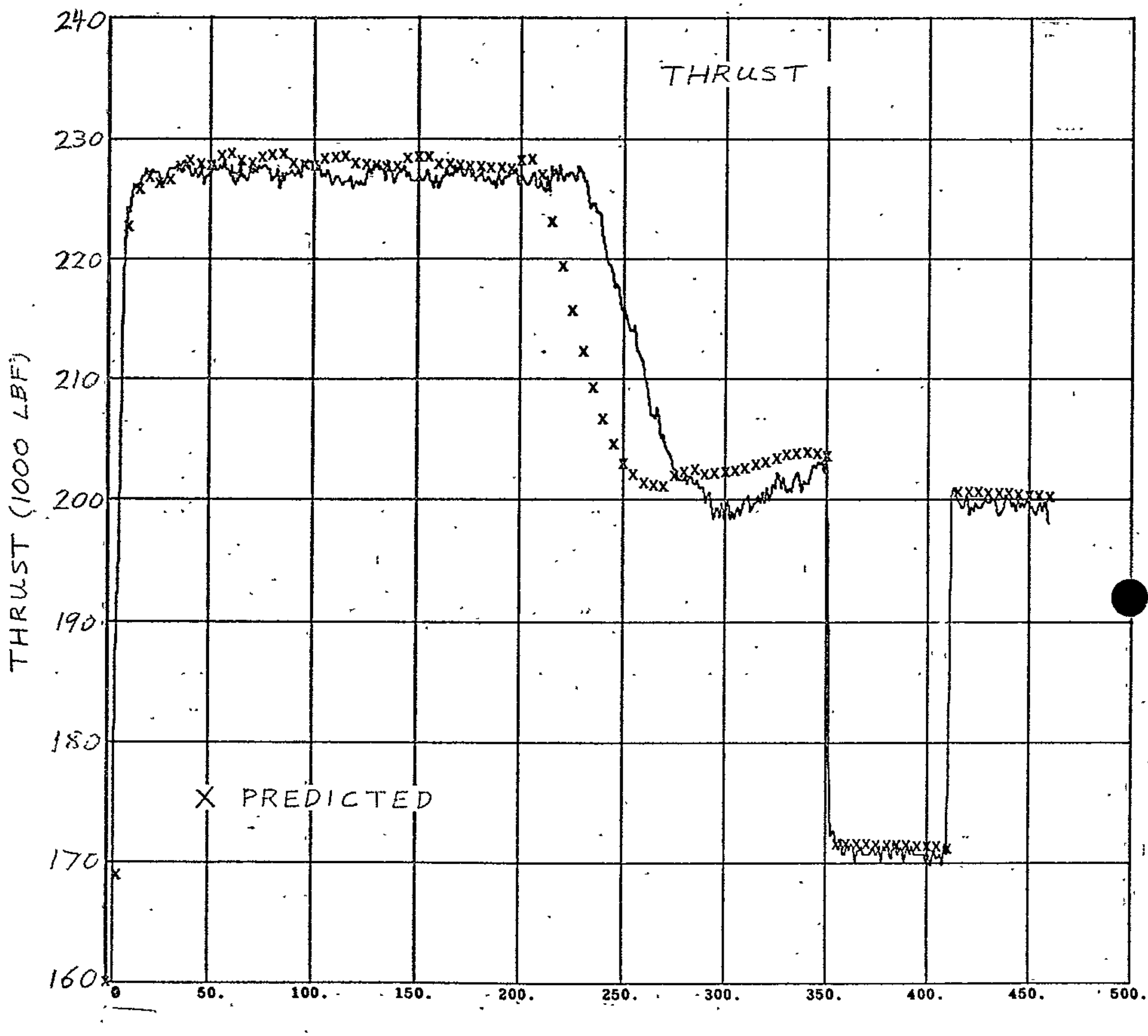


FIGURE 6-16. ENGINE STEADY STATE PERFORMANCE (SHEET 3 OF 3)

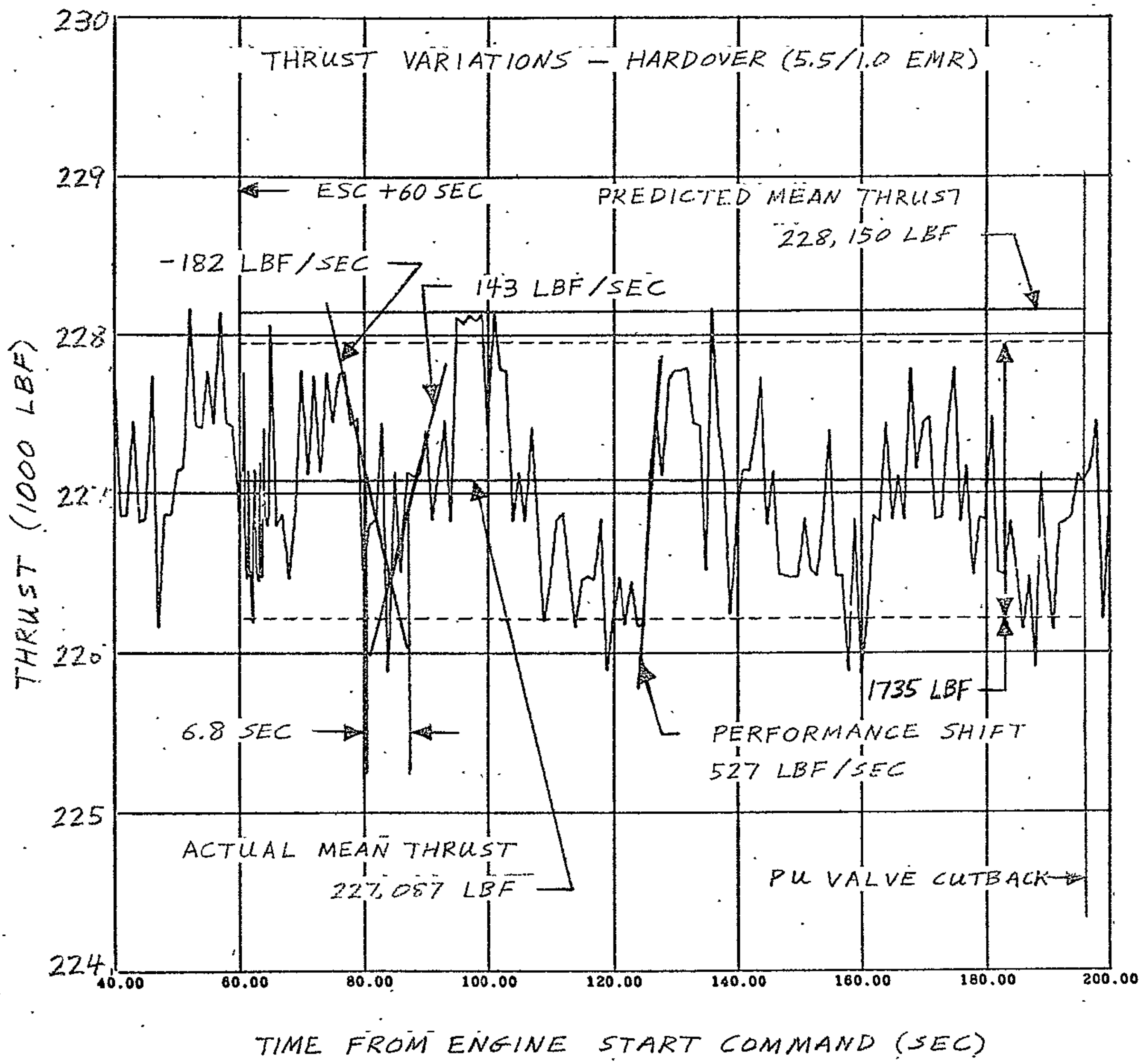


FIGURE 6-17. THRUST VARIATION (SHEET 1 OF 4)

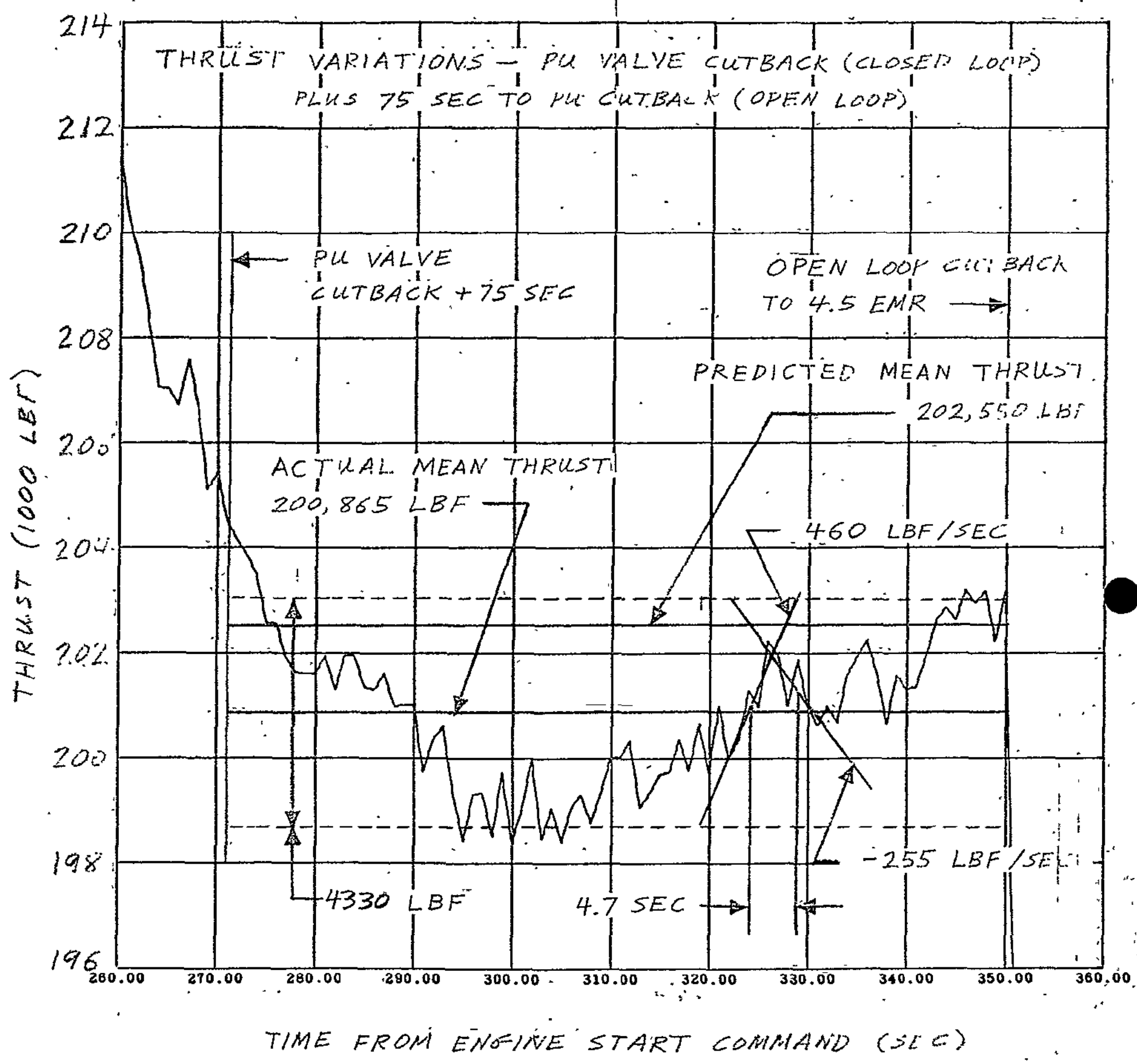


FIGURE 6-17. THRUST VARIATION (SHEET 2 OF 4)

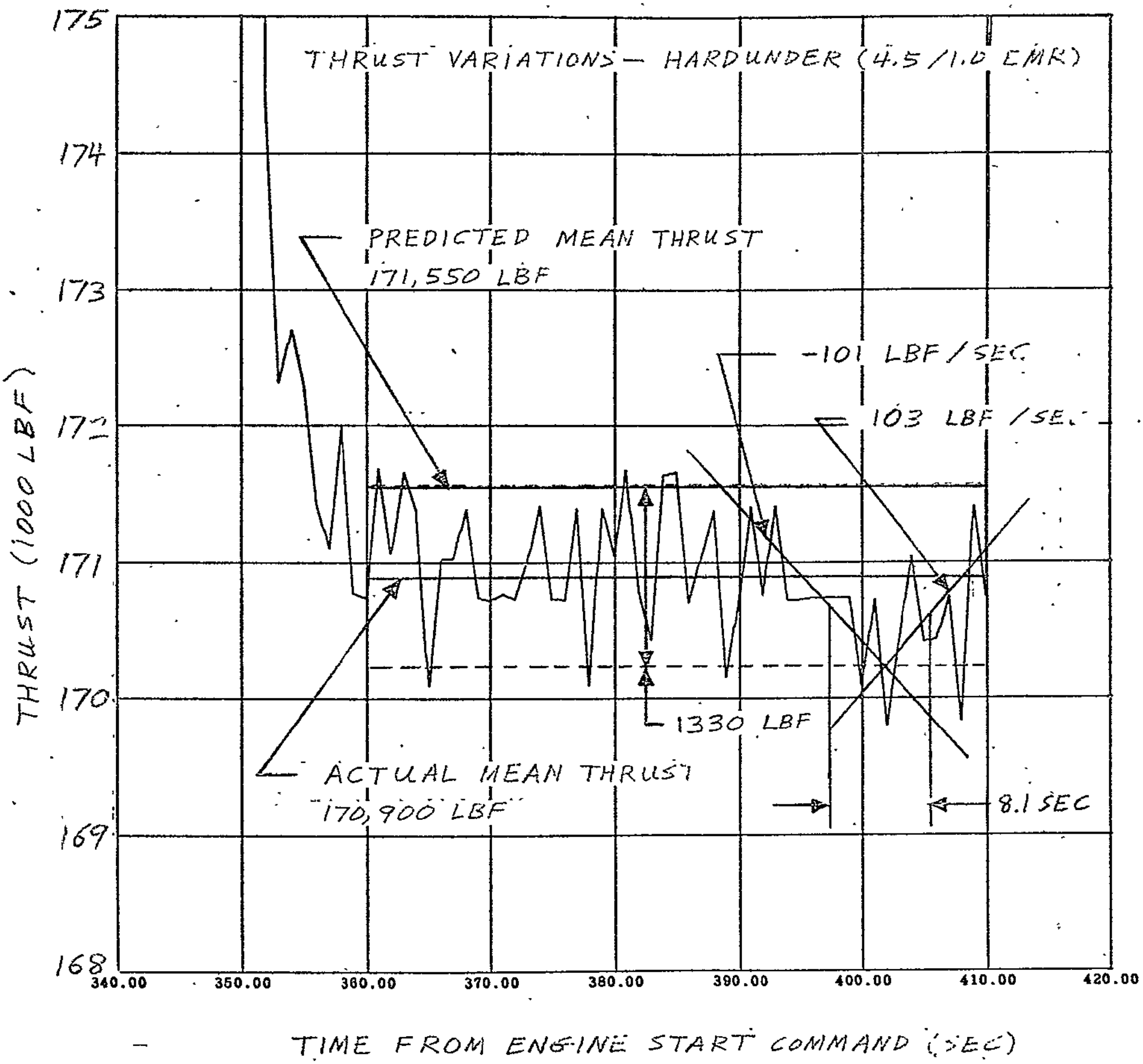


FIGURE 6-17. THRUST VARIATION (SHEET 3 OF 4)

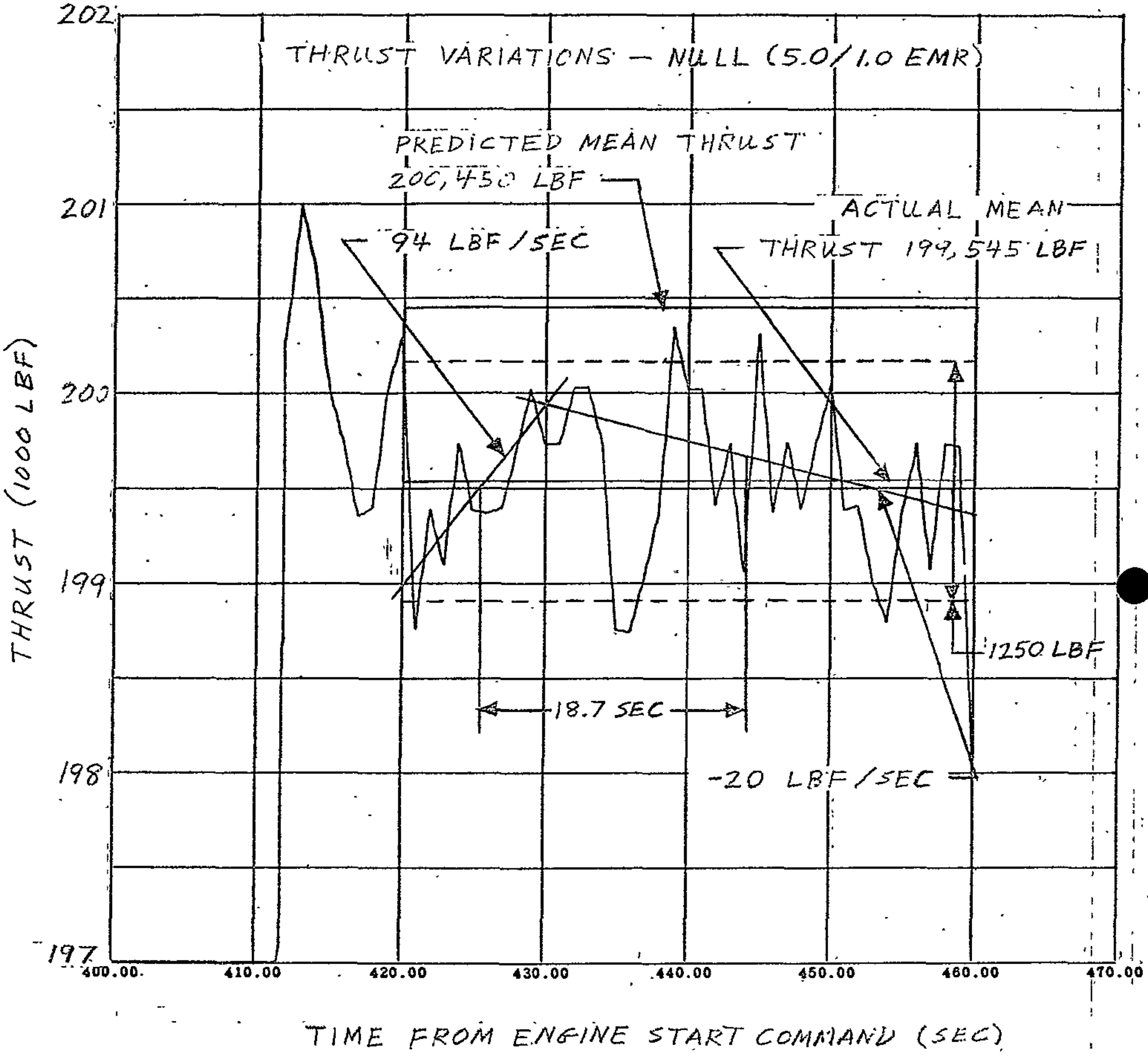


FIGURE 6-17. THRUST VARIATION (SHEET 4 OF 4)

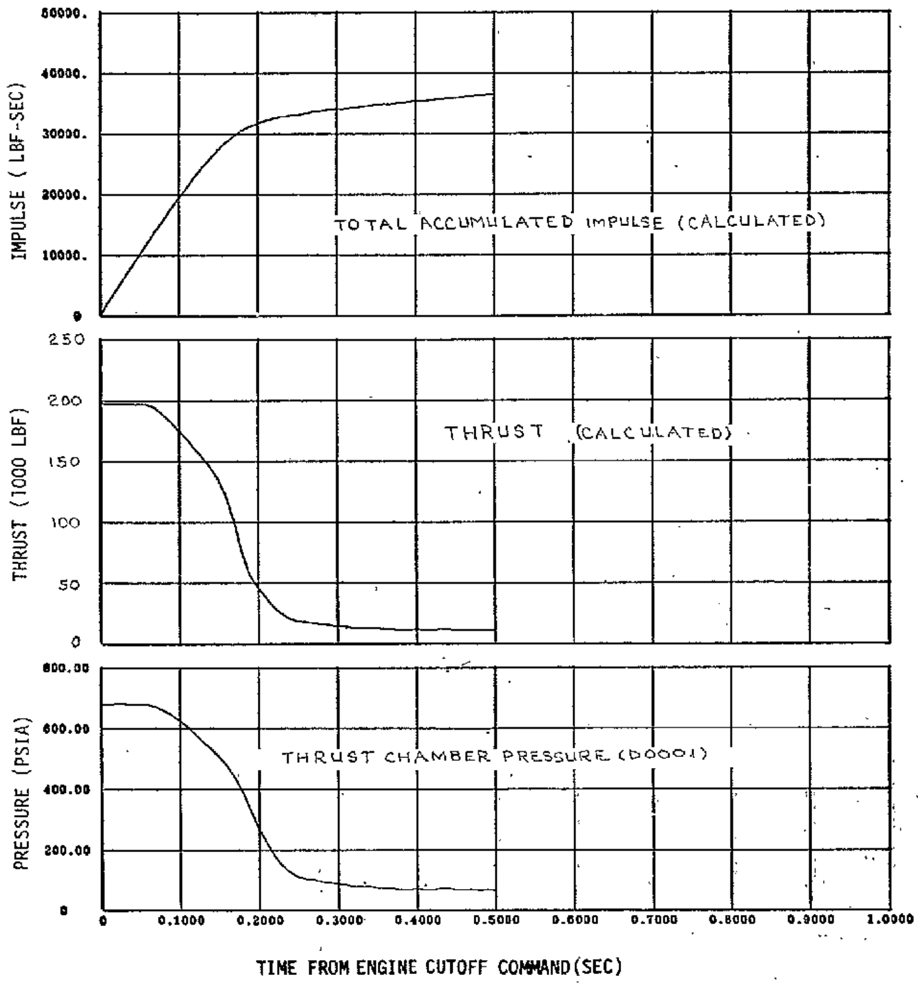


Figure 6-18 Engine Cutoff Transient Characteristics

EVENTS

IGNITION PHASE
- ENGINE START COMMAND P/U
- HELIUM CONTROL SOLENOID ENERGIZE P/U
- THRUST CHAMBER SPARK ON P/U
- GAS GENERATOR SPARK ON P/U
- IGNITION PHASE CONT SOLENOID ENERG P/U
- ASI LOX VALVE OPEN P/U
- LOX BLEED VALVE CLOSED P/U
- LH2 BLEED VALVE CLOSED P/U
- MAIN FUEL VALVE CLOSED D/O
- MAIN FUEL VALVE OPEN P/U
- ENGINE START COMMAND D/O

PUMP SPIN PHASE
- START TANK DISCH CONT SOLENOID ENERG P/U
- START TANK DISCHARGE VALVE CLOSED D/O
- START TANK DISCHARGE VALVE OPEN P/U

MAINSTAGE PHASE
- MAINSTAGE CONTROL SOLENOID ENERGIZE P/U
- START TANK DISCH CONT SOLENOID ENERG D/O
- MAIN LOX VALVE CLOSED D/O
- GAS GENERATOR VALVE CLOSED D/O
- START TANK DISCHARGE VALVE OPEN D/O
- GAS GENERATOR VALVE OPEN P/U
- LOX TURBINE BYPASS VALVE OPEN D/O
- START TANK DISCHARGE VALVE CLOSED P/U
- LOX TURBINE BYPASS VALVE CLOSED P/U
- MAINSTAGE PRESS. SWITCH NO. 1 PRESS. P/U
- MAINSTAGE PRESS. SWITCH NO. 2 PRESS. P/U
- MAIN LOX VALVE OPEN P/U
- THRUST CHAMBER SPARK ON D/O
- GAS GENERATOR SPARK ON D/O

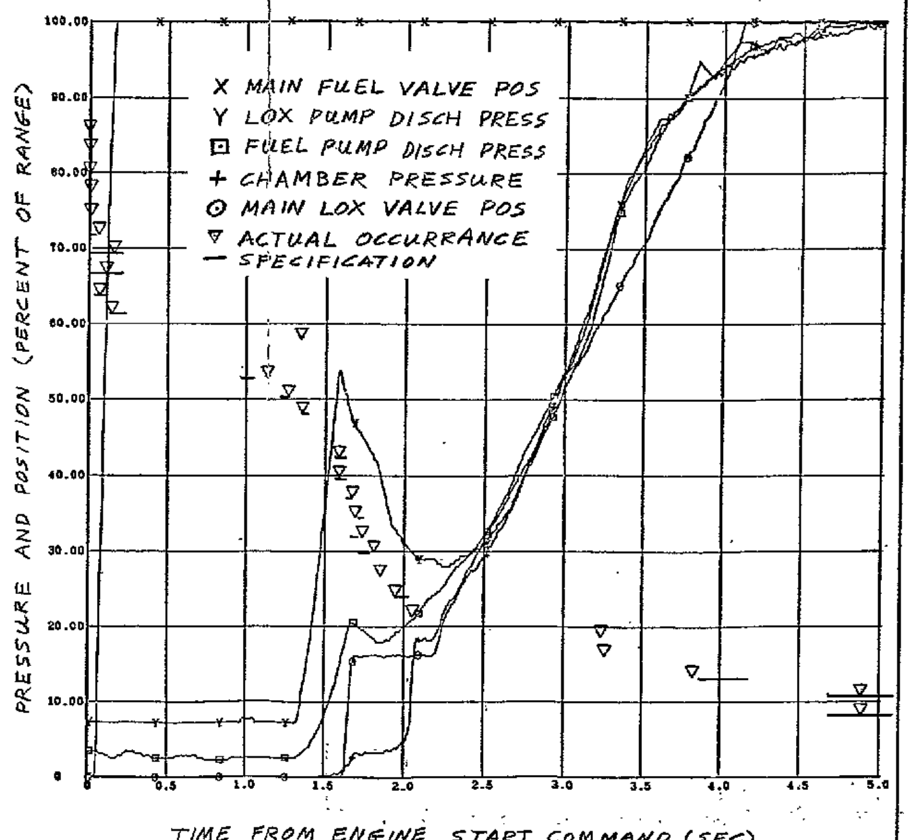


FIGURE 6-19. ENGINE START SEQUENCE

FOLDOUT FRAME 1

FOLDOUT FRAME 2

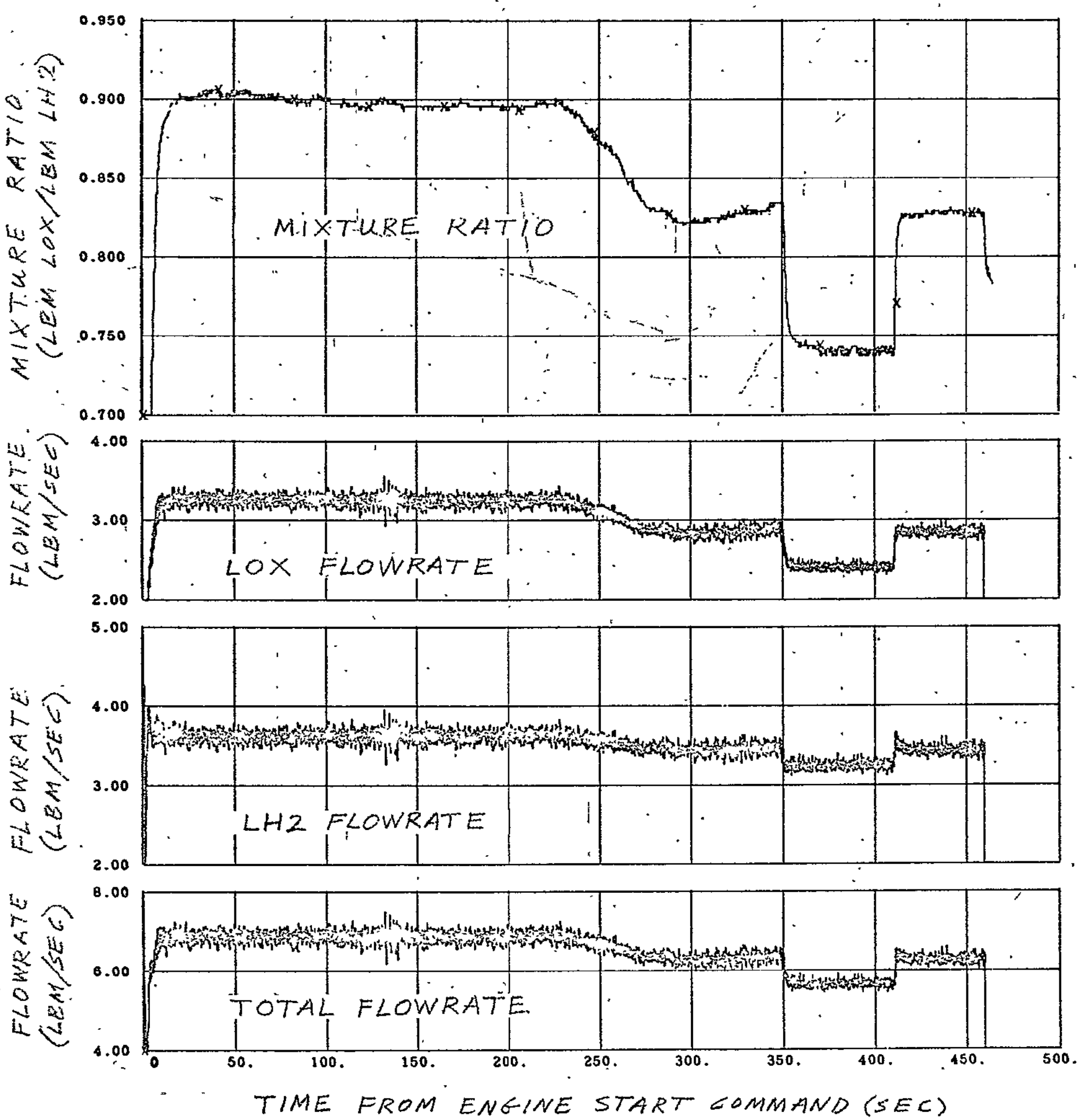


FIGURE 6-20. GAS GENERATOR PERFORMANCE

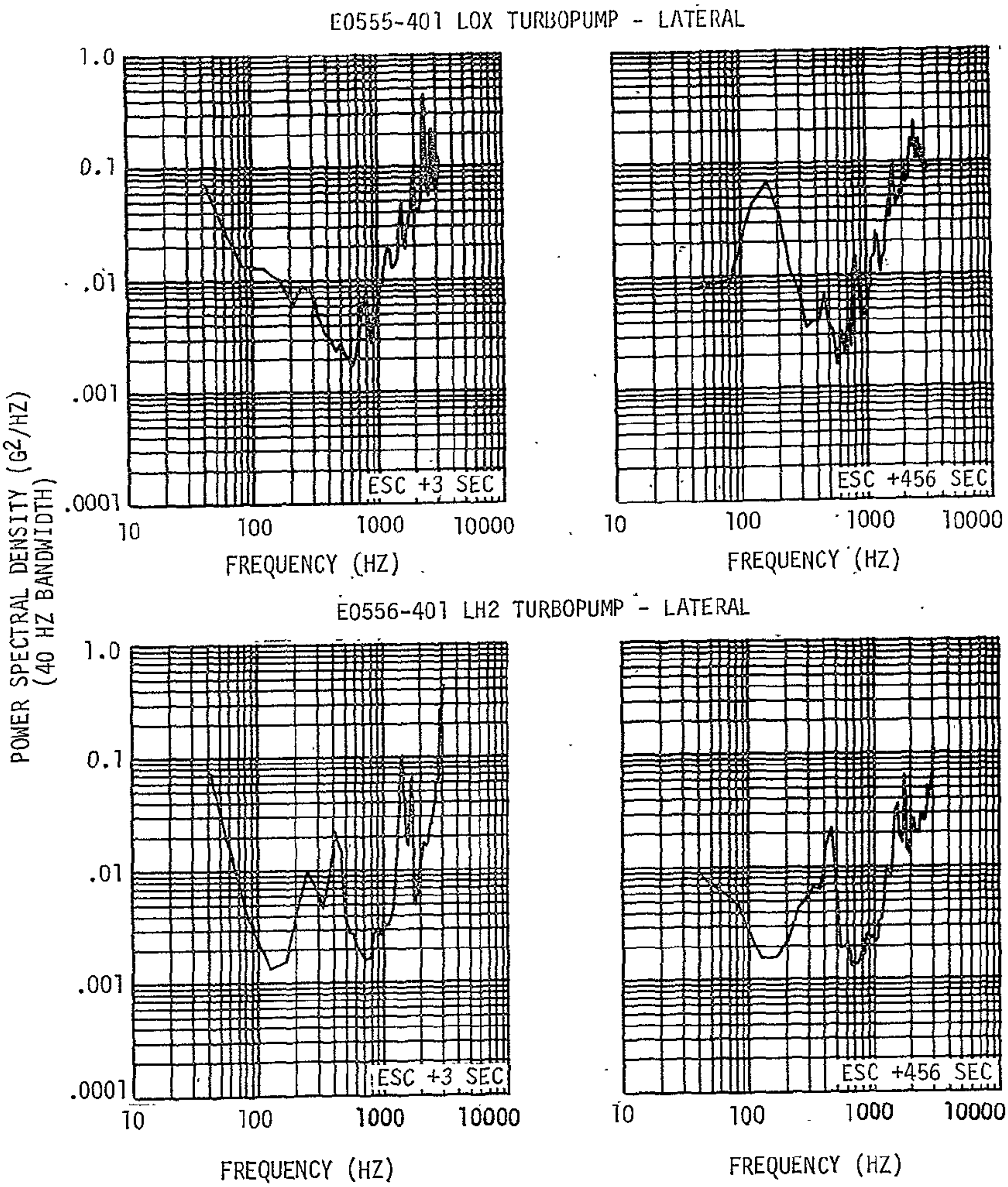


Figure 6-21. Engine Turbopump Vibration

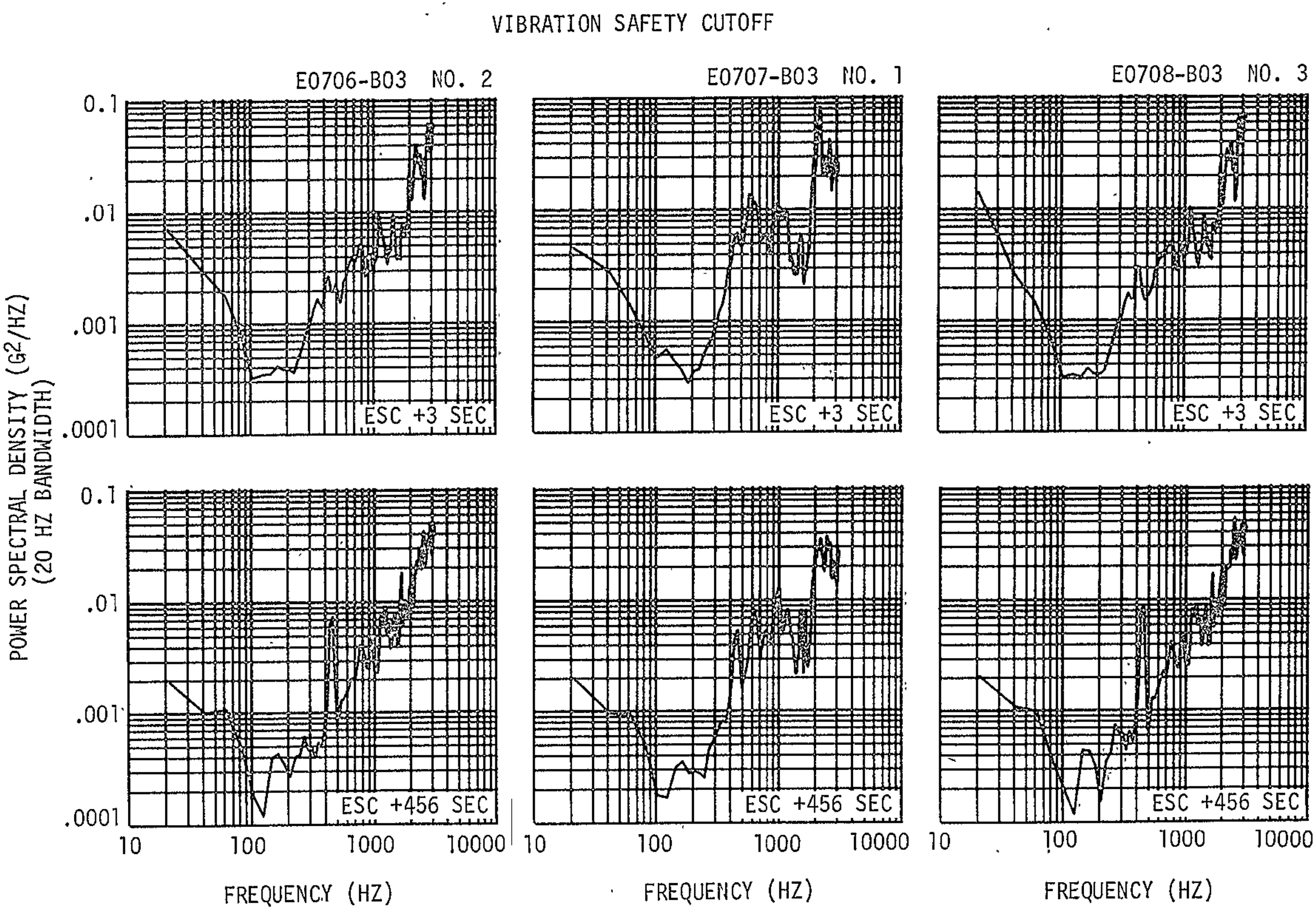


Figure 6-22. Engine Chamber Dome Vibration

SECTION 7

OXIDIZER SYSTEM

7. OXIDIZER SYSTEM

The oxidizer system functioned adequately, supplying LOX to the engine pump inlet within the specified limits. The net positive suction pressure (NPSP) available at the LOX pump inlet exceeded the engine manufacturer's minimum requirement at all times.

7.1 Pressurization Control

The LOX tank pressurization system (figure 3-1) satisfactorily maintained pressure in the LOX tank throughout the acceptance firing, and all portions of the system performed within the design requirements.

7.1.1 Prepressurization

LOX tank prepressurization and the pressure makeup cycle before simulated liftoff (SLO) were accomplished from ground support equipment (GSE) cold helium supply (figure 7-1). The LOX tank pressure increased from 39.0 psia to 42.0 psia due to an ullage volume decrease (caused by the common bulkhead depression and stage geometric changes that occur during LH2 tank prepressurization) and to the helium purges of the vent valve and the LOX tank ullage pressure sensing line.

In the course of simulated boost, the ullage pressure decayed to 38.4 psia. This pressure decay was caused by cooling ullage gas which resulted from heat transfer with the colder common bulkhead.

Significant LOX tank prepressurization data are compared with that from two previous acceptance firings in table 7-1.

7.1.2 Pressurization

The LOX tank pressurization system performance was satisfactory during engine operation (figure 7-2) and compared reasonably well with that from previous stages.

The modified LOX tank pressurization sequence utilized during the 506N and 507 acceptance tests was also used for the 508 test. The cold helium shutoff valves were opened at ESC -2.4 seconds, increasing the ullage

pressure from 38.4 to 42.0 psia by engine start command. During this 2.4-second period, 0.5 lbm of helium was added to the LOX tank ullage. The heat exchanger control valve was programmed to the open position during cold helium lead and during the first 21 seconds after engine start command. The resulting higher initial flowrate completely eliminated the tendency for LOX tank ullage pressure dip. Following the enabling of the heat exchanger control valve, overcontrol flow was required seven times to maintain the ullage pressure within the range of 38.3 to 40.0 psia during the firing.

The S-IVB-508 stage LOX tank pressurization system data are compared with that from the S-IVB-506N and 507 acceptance firings in table 7-2.

7.1.3 O_2-H_2 Burner Repressurization

LOX tank repressurization was performed during a test utilizing the O_2-H_2 burner and pressurant helium from the cold helium spheres. The tank was filled to a nominal second start level and prepressurized to 34.5 psia to simulate the burner inlet conditions expected during burner start and subsequent repressurization. The tank conditions are shown in figure 7-3; significant data are compared to that from previous firings in table 7-3. Data are also presented in section 10.

Burner start was followed by a short lag before the initiation of LOX tank repressurization in order to provide higher burner chamber pressure (and improved combustion stability) during the start transient.

7.1.4 Ambient Repressurization

After burner repressurization, the ambient repressurization test was performed. The LOX tank was loaded to approximately 68 percent to simulate the load expected during orbital restart. The test data are presented in figure 7-4.

The ambient repressurization system performance during the S-IVB-508 acceptance test is compared with that during the 506N and 507 acceptance tests in table 7-3. The value for helium usage shown in this table includes the flow through the pilot bleed port of the helium shutoff

valves. This pilot bleed flow, which amounts to about 6% of the total usage, is dumped overboard by venting directly from the ambient repressurization module.

7.2 Cold Helium Supply

The cold helium spheres were the source of the pressurant for both propellant tanks during O2-H2 burner operation and for the LOX tank during J-2 engine operation.

The system performance during the O2-H2 burner firing is discussed in paragraph 10.4.

During J-2 engine operation, demands on the cold helium system were normal and adequately met. The sphere pressure (2,845 psia) at engine start command was well within the start requirement of 2,600 $\pm$600 psia. Since cold helium sphere pressure transducers (D0016 and D0248) were not on the stage, the cold helium manifold pressures (D0261 and D0263) were used for system evaluation. Data are presented in figure 7-5 and table 7-4.

7.3 J-2 Heat Exchanger

The J-2 heat exchanger functioned satisfactorily (figure 7-6). The heat exchanger pressures, temperatures, helium flowrates, and heat input rate are consistent with past experience. The LOX vent inlet pressure and the LOX tank diffuser temperature were comparable to previous test data. Table 7-5 compares significant 508 acceptance data with that from two previous acceptance firings.

7.4 LOX Pump Chilldown

The LOX pump chilldown system performance was adequate. At engine start command, the NPSP at the LOX pump inlet was above the minimum 11.9 psi required at that time. The results of the chilldown performance calculations are presented in figures 7-7 and 7-8; significant chilldown system data are compared with 506N and 507 data in table 7-6.

The chilldown pump was started at SLO -288.7 seconds in order to simulate conditions during the flight countdown. The chilldown shutoff valve was left open until ESC +411 seconds.

For the calculation of heat input to the LOX chilldown system, the normal reference temperature for section 1 (tank to engine pump inlet) is the chilldown pump discharge temperature (C0163). This assumes no heat input from the tank to the chilldown pump outlet. Since C0163 was not installed on 508, the LOX bulk temperature (C0040) was used with a bias for constructing the chilldown pump discharge temperature.

7.5 Engine LOX Supply

The LOX supply system (figure 3-1) delivered the necessary quantity of LOX to the engine pump inlet throughout the engine firing and maintained the pressure and temperature conditions within a range that provided a LOX pump NPSP above the minimum requirements. The data and the calculated performance are presented in figure 7-9 and are compared with that from two previous acceptance firings in table 7-7.

During engine operation, the LOX pump inlet pressure and temperature were near the predicted values. Both were plotted in the engine LOX pump operating region (figure 7-10) and showed that the LOX pump inlet conditions were satisfactory throughout engine operation.

In figure 7-11, the LOX pump inlet temperature is plotted against the mass remaining in the tank during engine operation and compared to the 506N and 507 acceptance firing data. The data used for comparison have been biased to the LOX pump inlet temperature observed at engine start command of the S-IVB-508 acceptance firing to correct for instrumentation error, differences in heating during pressurization, and other test-to-test variations.

TABLE 7-1

LOX TANK PREPRESSURIZATION DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Prepressurization duration (sec)	10.4	13.1	10.5
Number of makeup cycles before SLO	1	2	1
Number of makeup cycles after SLO	0	2	2
Prepressurization helium			
Average flowrate (lbm/sec)	0.35	0.31	0.44
Mass added to LOX tank during prepressurization* (lbm)	3.65	4.11	4.58
Mass added to LOX tank during makeup cycles before SLO (lbm)	1.0	2.0	1.61
Mass added to LOX tank during makeup cycles after SLO (lbm)	0	1.16	0.59
Ullage pressure			
At prepressurization initiation (psia)	14.8	15.1	14.9
At prepressurization termination (psia)	41.1	41.0	41.0
At engine start command (psia)	42.0	42.6	43.1
Events (sec from SLO)			
Prepressurization initiation	-163.76	-163.88	-164.38
Prepressurization termination	-153.41	-150.83	-153.91
Engine start command	511.693	511.758	511.378

* Does not include any makeup cycles.

TABLE 7-2

LOX TANK PRESSURIZATION DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Number of overcontrol cycles*	8	7	8
Pressure control band			
Minimum (psia)	38.3	38.2	38.6
Maximum (psia)	40.0	40.3	40.5
Ullage pressure			
At pressurization initiation (psia)	38.4	40.0	39.4
At engine start command (psia)	42.0	42.6	43.1
Minimum during start transient (psia)	38.3	38.3	38.5
At engine cutoff command (psia)	40.6	39.1	39.6
Total pressurant flowrate			
Overcontrol (lbm/sec)	0.34 to 0.44	0.35 to 0.42	0.32 to 0.43
Undercontrol (lbm/sec)	0.25 to 0.32	0.24 to 0.31	0.24 to 0.32

*Includes the programmed overcontrol cycle during the start transient.

TABLE 7-3

LOX TANK REPRESSURIZATION DATA

Parameter	S-IVB-508		S-IVB-507		S-IVB-506N	
	Ambient	Burner	Ambient	Burner	Ambient	Burner
Repressurization duration (sec)	84	171*	75	151*	118	201*
Number of makeup cycles	0	0	0	0	0	0
Repressurization helium						
Usage** (lbm)	9.2	3.6	9.7	3.8	11.5	5.5
Average flowrate (lbm/sec)	0.109	0.021	0.129	0.0252	0.0974	0.025
Orifice effective area*** (in.^{2})	0.00888	0.00568	0.00890	0.00566	0.00858	0.00565
Ullage pressure						
At repressurization initiation (psia)	31.6	34.5	31.7	33.7	31.5	34.7
At repressurization termination (psia)	40.0	37.9	40.4	36.5	40.3	38.6
Rise rate (psi/min)	6.00	1.19	6.96	1.11	4.47	1.16

* Does not include the lag in repressurization initiation following burner start command.

** These values include the flow through the pilot bleed ports of the helium shutoff valves. See paragraphs 7.1.4 and 10.5 for further information.

*** Does not include the pilot bleed orifice effective area (0.00054 in.^{2}).

TABLE 7-4

COLD HELIUM SUPPLY DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Pressure			
Simulated liftoff (psia)	2,975	2,993	2,806
Engine start command (psia)	2,845	2,838	2,664*
Engine cutoff command (psia)	1,000	1,050	1,021
Average temperature			
Simulated liftoff (deg R)	40.0	41.2	41.6
Engine start command (deg R)	39.3	41.0	40.8*
Engine cutoff command (deg R)	44.1	44.0	43.8
Helium mass			
Engine start command (lbm)	367	368	360*
Engine cutoff command (lbm)	208	216	211
Helium consumption			
Calculated from sphere conditions (lbm)	159	152	149**
Calculated from flowrate integration (lbm)	151	141	145**

* At ESC -2.4 seconds, when LOX tank pressurization was initiated.

** Includes 2.4 seconds of flow prior to engine start command.

*** Low because of cold helium leak.

TABLE 7-5

J-2 HEAT EXCHANGER DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Flowrate through heat exchanger			
During overcontrol (lbm/sec)	0.21	0.20	0.20
During undercontrol (lbm/sec)	0.093	0.090	0.085
Heat exchanger outlet temperature			
At end of 50-sec transient (deg R)	870	930	960
During overcontrol (deg R)	880	950	980
During undercontrol (deg R)	910	970	1,000
At engine cutoff command (deg R)	860	950	962
Heat exchanger outlet pressure			
During overcontrol (psia)	340	340	350
During undercontrol (psia)	395	395	400
Average LOX vent inlet pressure			
During overcontrol (psia)	62	63	62
During undercontrol (psia)	48	49	48

TABLE 7-6

LOX CHILLDOWN SYSTEM PERFORMANCE DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
NPSP			
At engine start command (psi)	32.8	33.8	34.6
Minimum required at start (psi)	11.9	11.9	11.6
At opening of prevalve (psi)	33.9	40.0	39.7
Pump inlet conditions			
Pressure at engine start command (psia)	51.0	51.1	51.3
Temperature at engine start command (deg R)	164.7	165.1	164.5
Average flow coefficient (sec^2/in^2ft^3)	17.5	17.2	16.9
Heat absorption rate (Btu/hr)			
Section 1 (tank to pump inlet)	7,000	10,500	3,200
Section 2 (pump inlet to bleed valve)	16,000	6,500	14,500
Section 3 (bleed valve to tank)	6,000	5,000	1,800
Total	29,000	22,000	19,500
Chilldown flowrate			
Unpressurized (gpm)	40.0	39.5	39.4
Pressurized (gpm)	42.9	41.2	42.5
Chilldown system pressure differential			
Unpressurized (gpm)	10.0	9.5	9.8
Pressurized (gpm)	11.1	10.4	10.7

Table 7-6 (Continued)

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Events (sec from simulated liftoff)			
Chilldown initiation	-288.7	-288.6	-289.4
Prepressurization	-163.7	-163.9	-164.4
Prevalve open command	507.7	507.7	507.4
Prevalve closed signal dropout	508.5	508.7	508.6
Prevalve open signal pickup	509.8	510.4	510.2
Delay between prevalve open command and pickup of open signal	2.14	2.50	2.78
Engine start command	511.7	511.7	511.4
Chilldown shutoff valve closed	922.2	922.1	921.9

TABLE 7-7

LOX PUMP INLET CONDITION DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Pump inlet conditions			
Static pressure at engine start command (psia)	51.0	51.1	51.3
Temperature at engine start command (deg R)	164.7	165.1	164.5
Temperature at engine cutoff command (deg R)	166.4	166.8	166.3
NPSP requirements at pump interface			
Minimum at engine start command (psi)	11.9	11.9	11.6
At high EMR (psi)	20.0	20.0	19.8
After EMR cutback (psi)	14.0	14.0	14.7
NPSP available at pump interface			
At engine start command (psi)	33.9	33.8	34.6
Maximum during firing (psi)	33.9	33.8	34.6
Time of maximum (sec from engine start command)	0	0	0
Minimum during firing (psi)	23.3	19.0	22.4
Time of minimum (sec from engine start command)	460	436	448
At engine cutoff command (psi)	23.3	19.0	22.4
LOX feed duct			
At high EMR			
Pressure drop (psi)	2.0	1.4	2.0
Flowrate (lbm/sec)	454	465	460
After EMR cutback			
Pressure drop (psi)	1.1	0.9	1.2
Flowrate (lbm/sec)	390	422	400

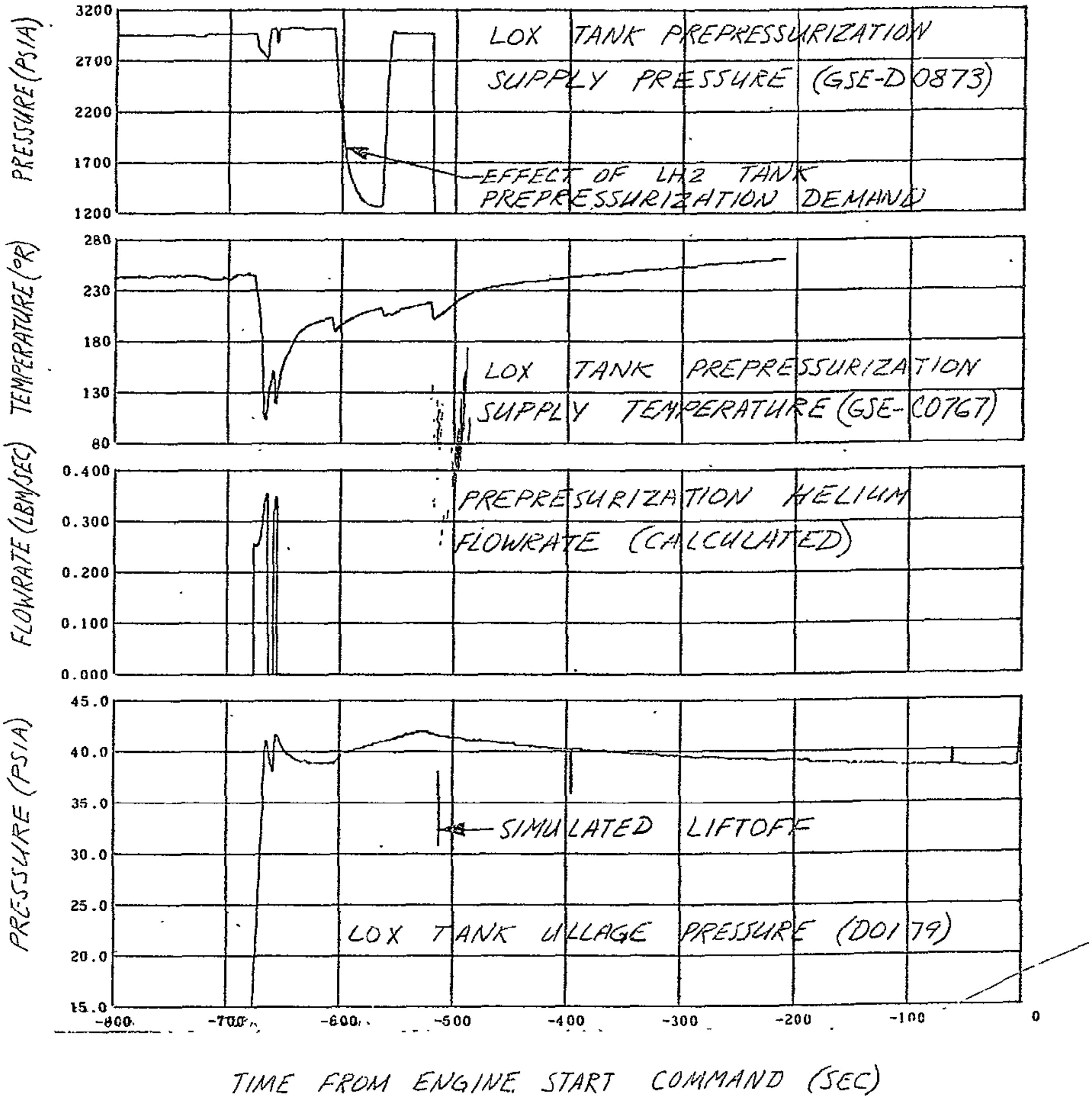


FIGURE 7-1. LOX TANK PREPRESSURIZATION

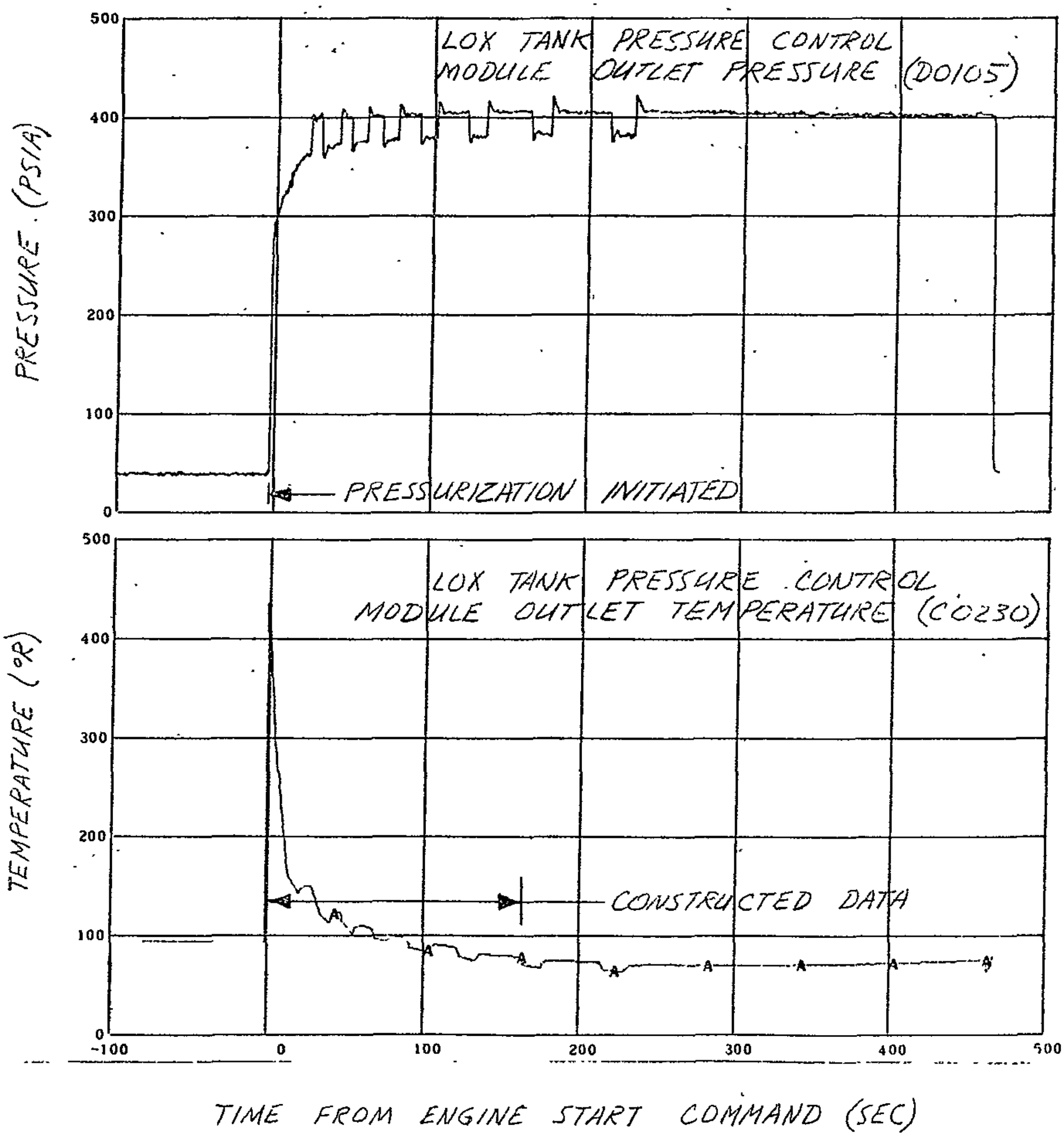


FIGURE 7-2. LOX TANK PRESSURIZATION SYSTEM PERFORMANCE (SHEET 1 OF 2)

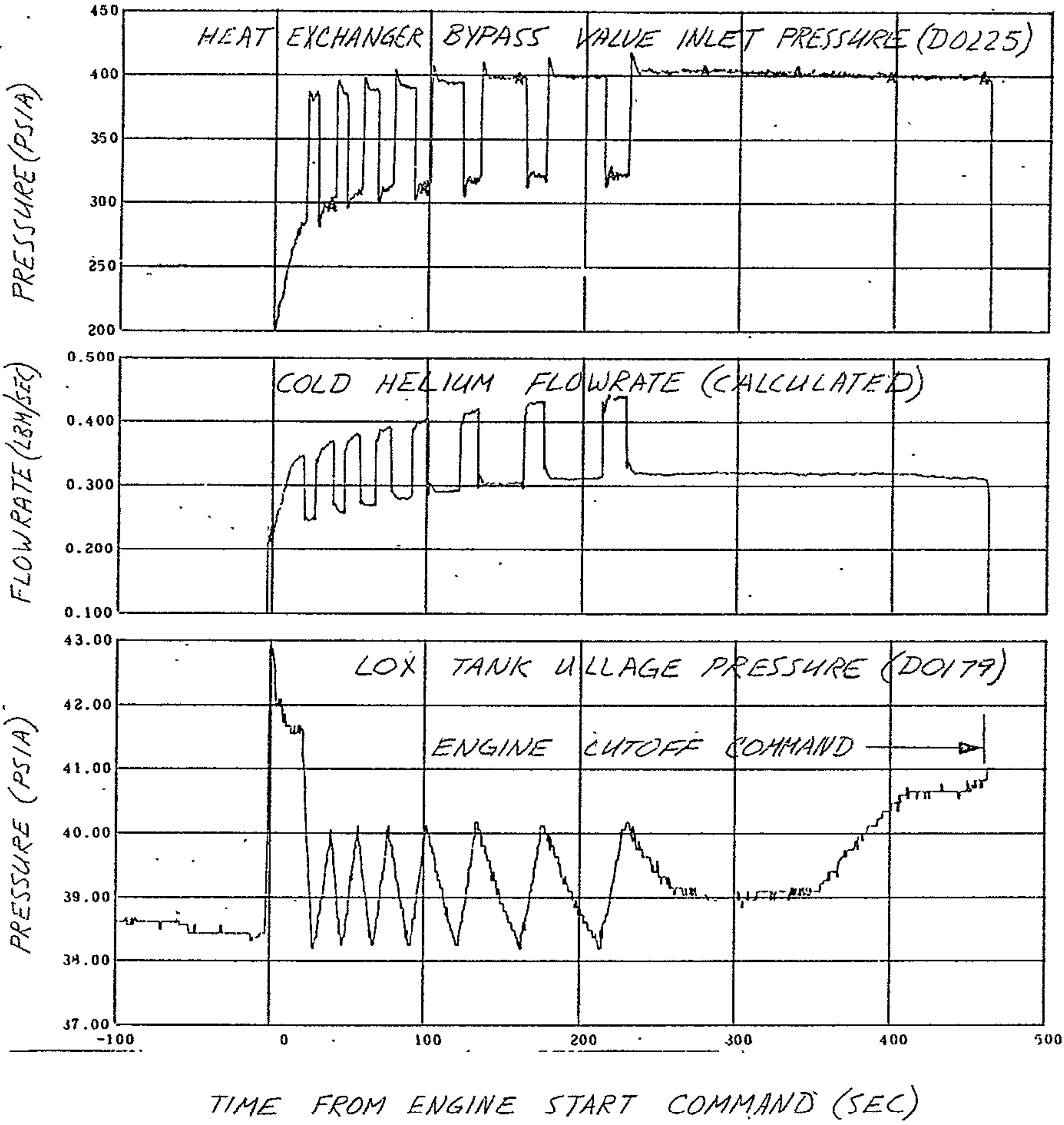


FIGURE 7-2. LOX TANK PRESSURIZATION SYSTEM PERFORMANCE (SHEET 2 OF 2)

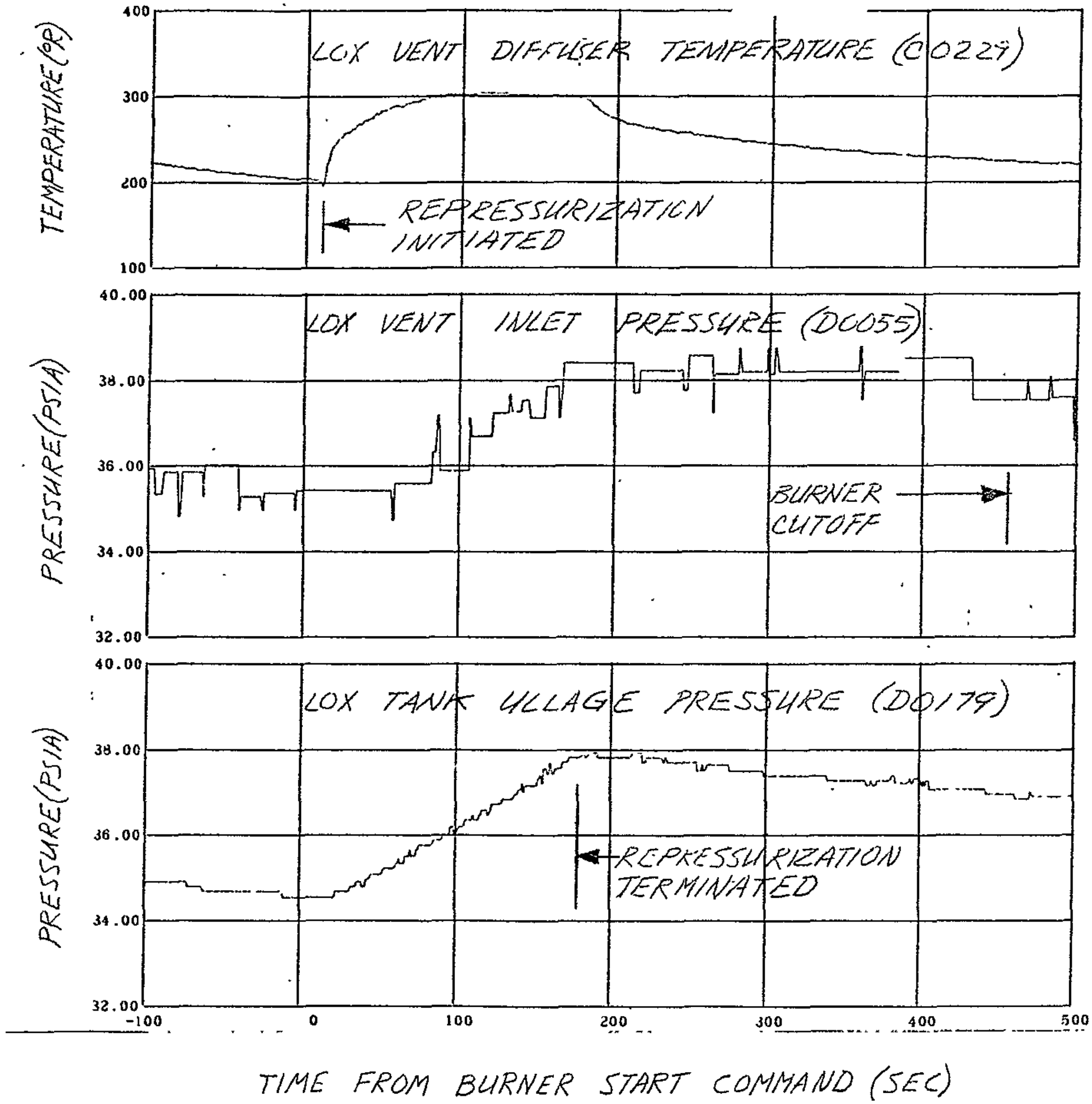


FIGURE 7-3. LOX TANK O2-H2 BURNER REPRESSURIZATION

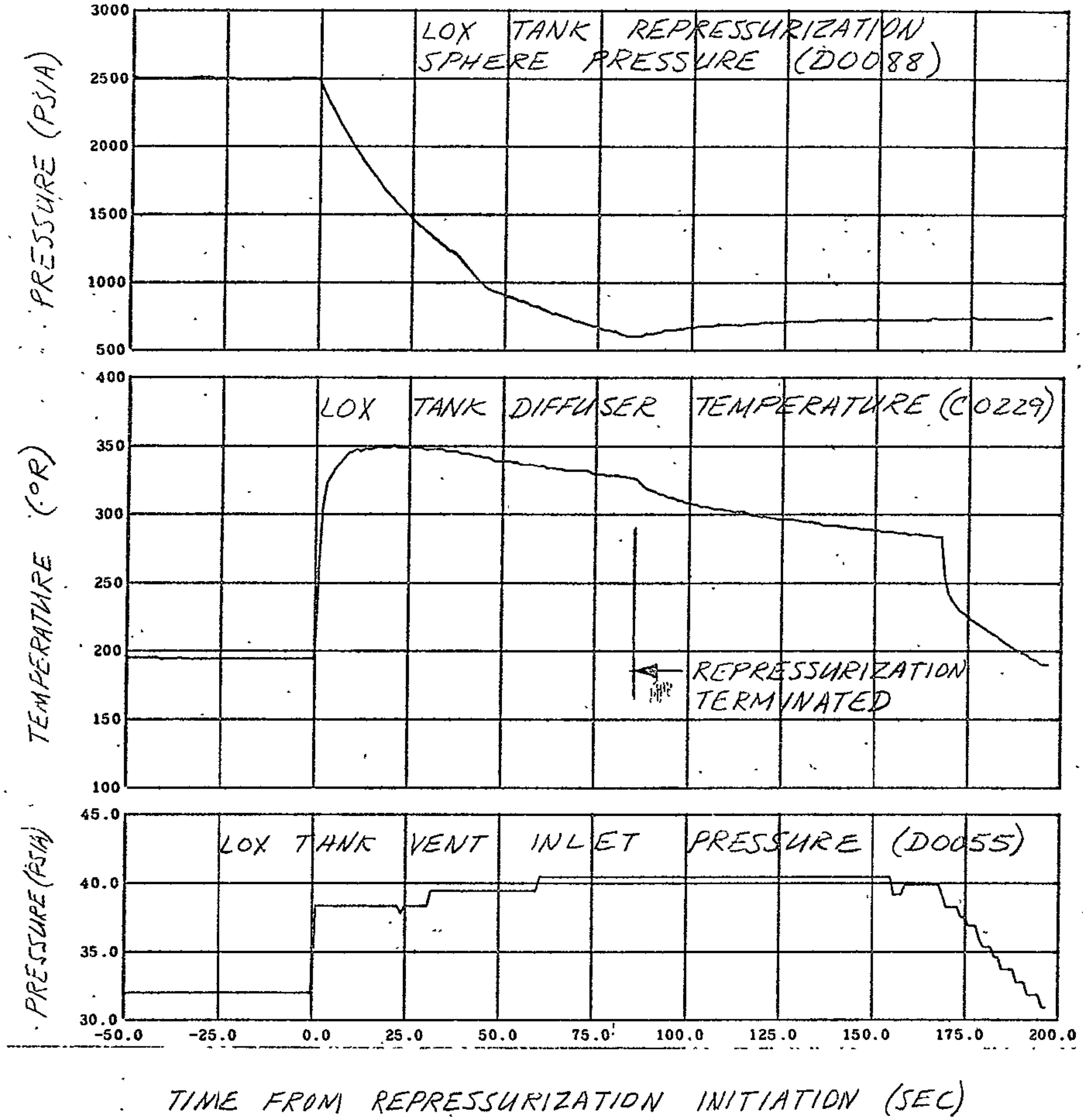


FIGURE 7-7. LOX TANK AMBIENT HELIUM REPRESSURIZATION
(SHEET 1 OF 2)

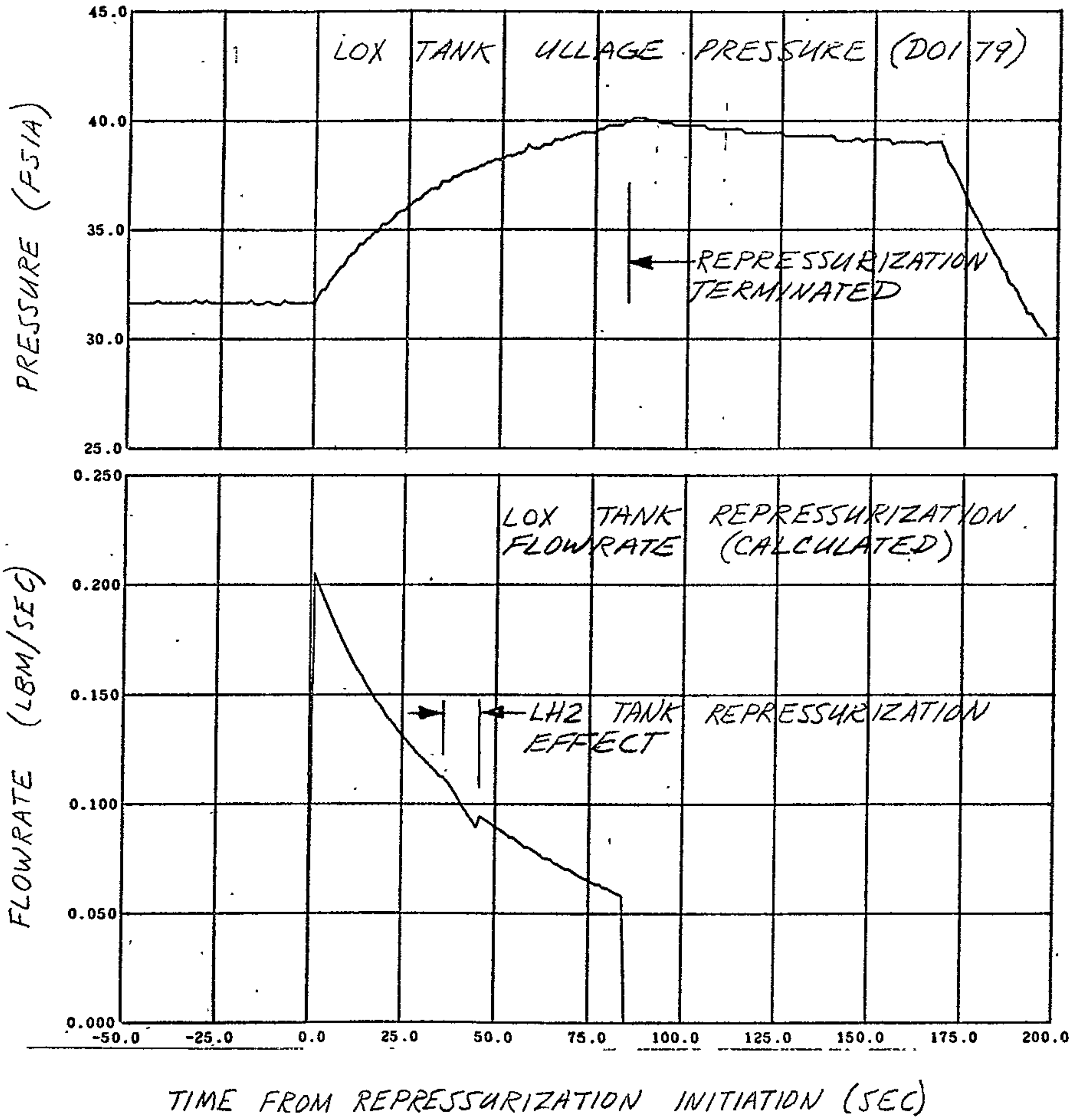


FIGURE 7-4. LOX TANK AMBIENT HELIUM REPRESSURIZATION (SHEET 2 OF 2)

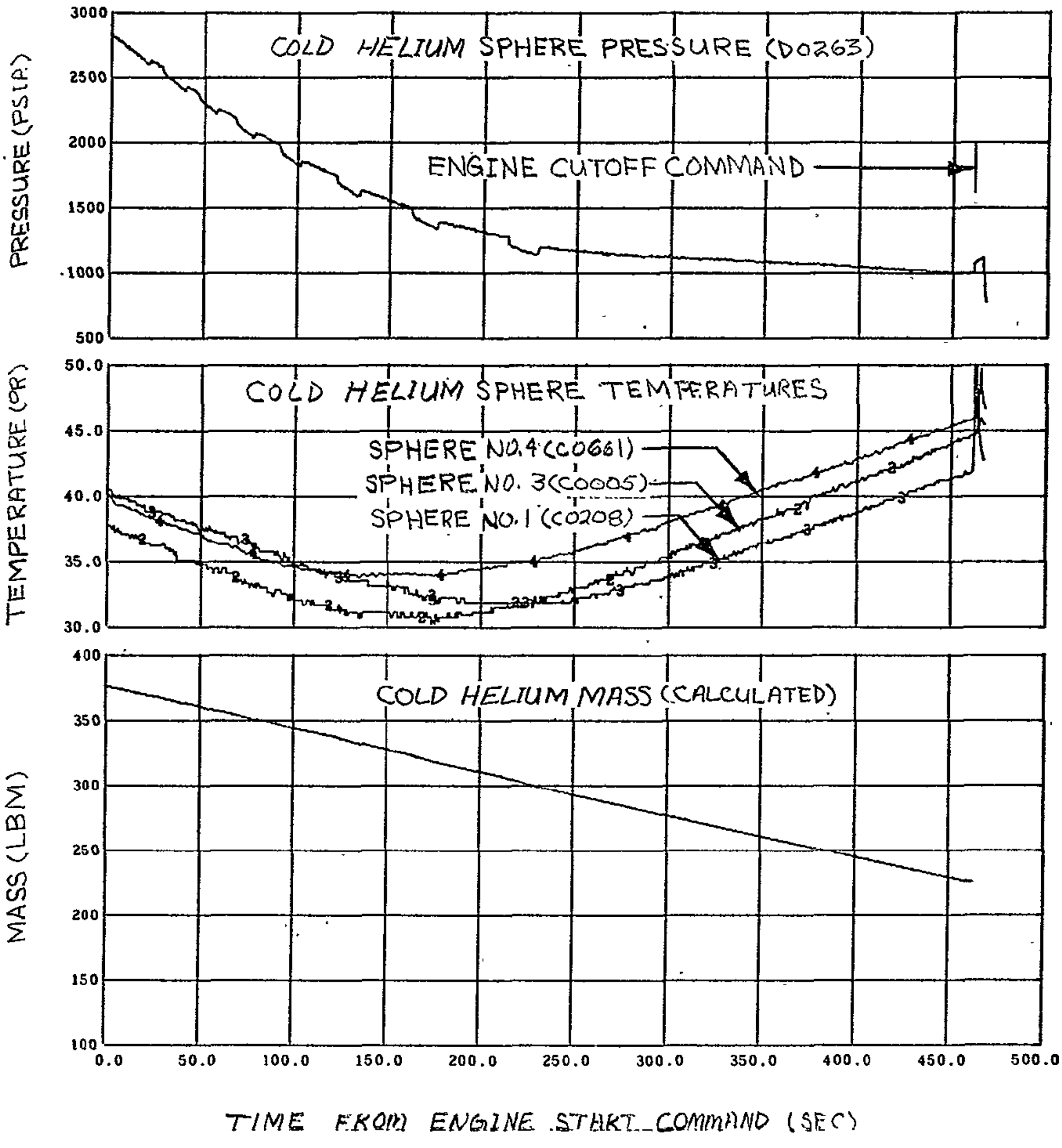


FIGURE 7-5. COLD HELIUM SUPPLY

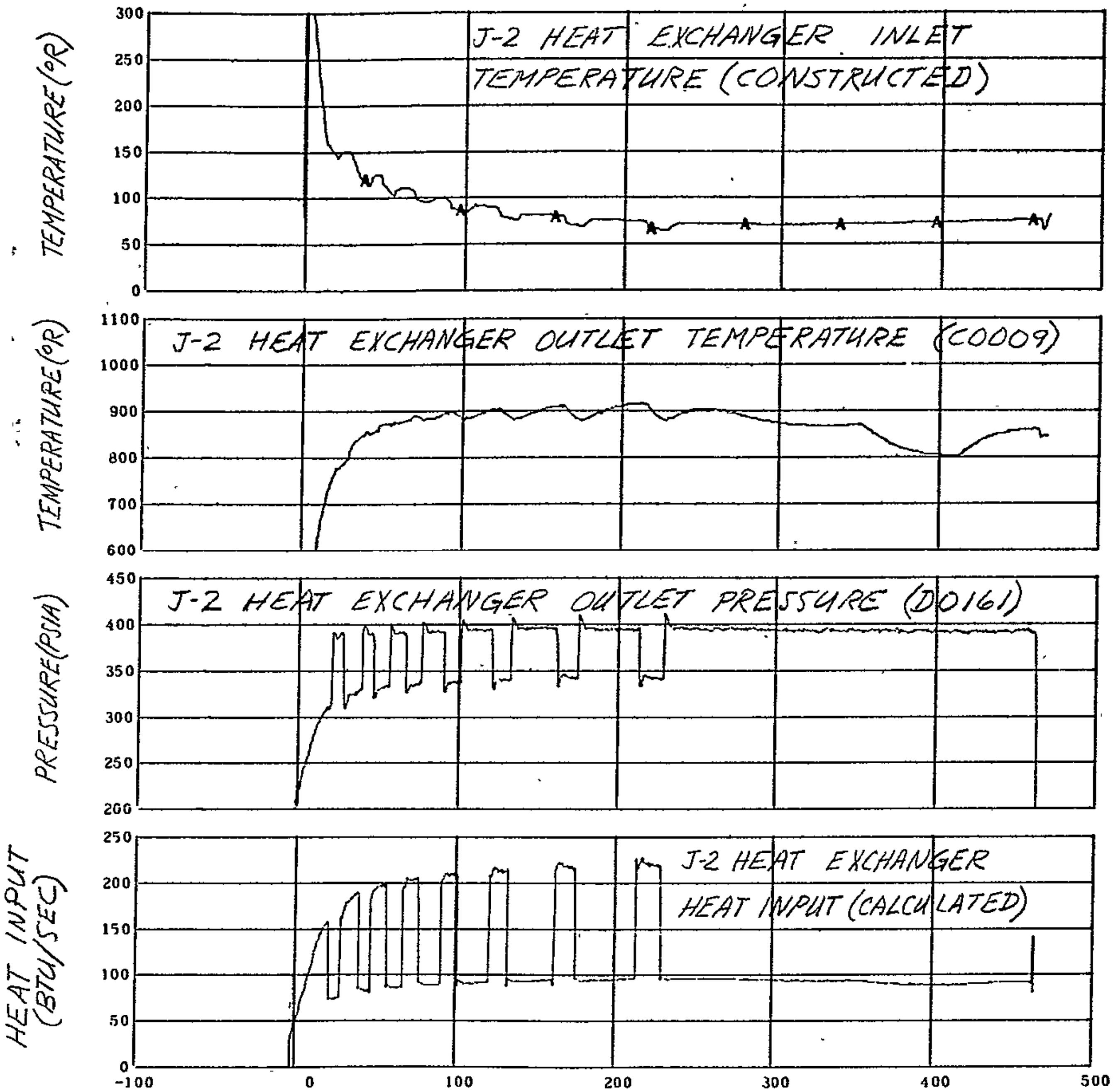


FIGURE 7-6. J-2 HEAT EXCHANGER PERFORMANCE (SHEET 1 OF 2)

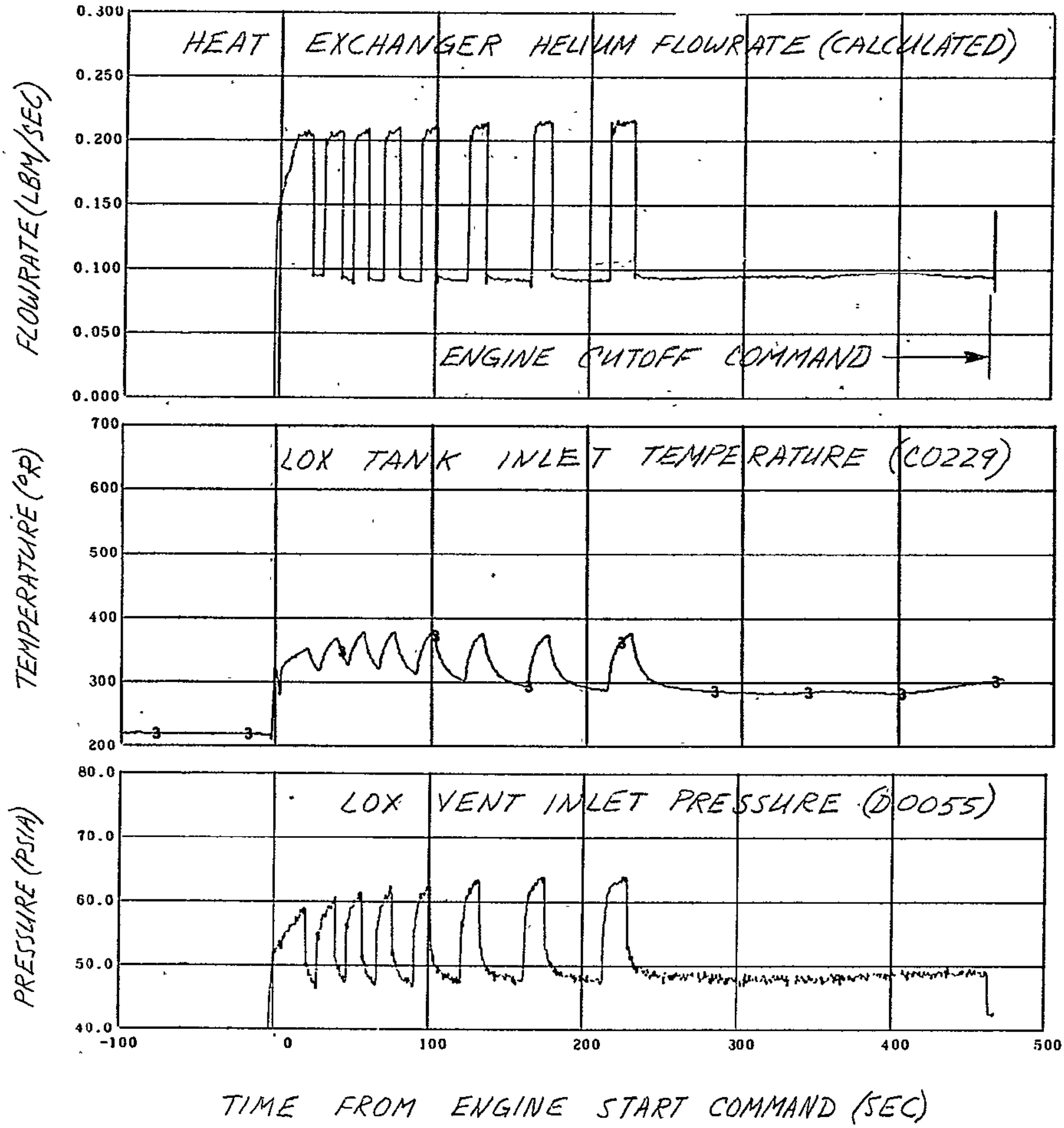


FIGURE 7-6. J-2 HEAT EXCHANGER PERFORMANCE
(SHEET 2 OF 2)

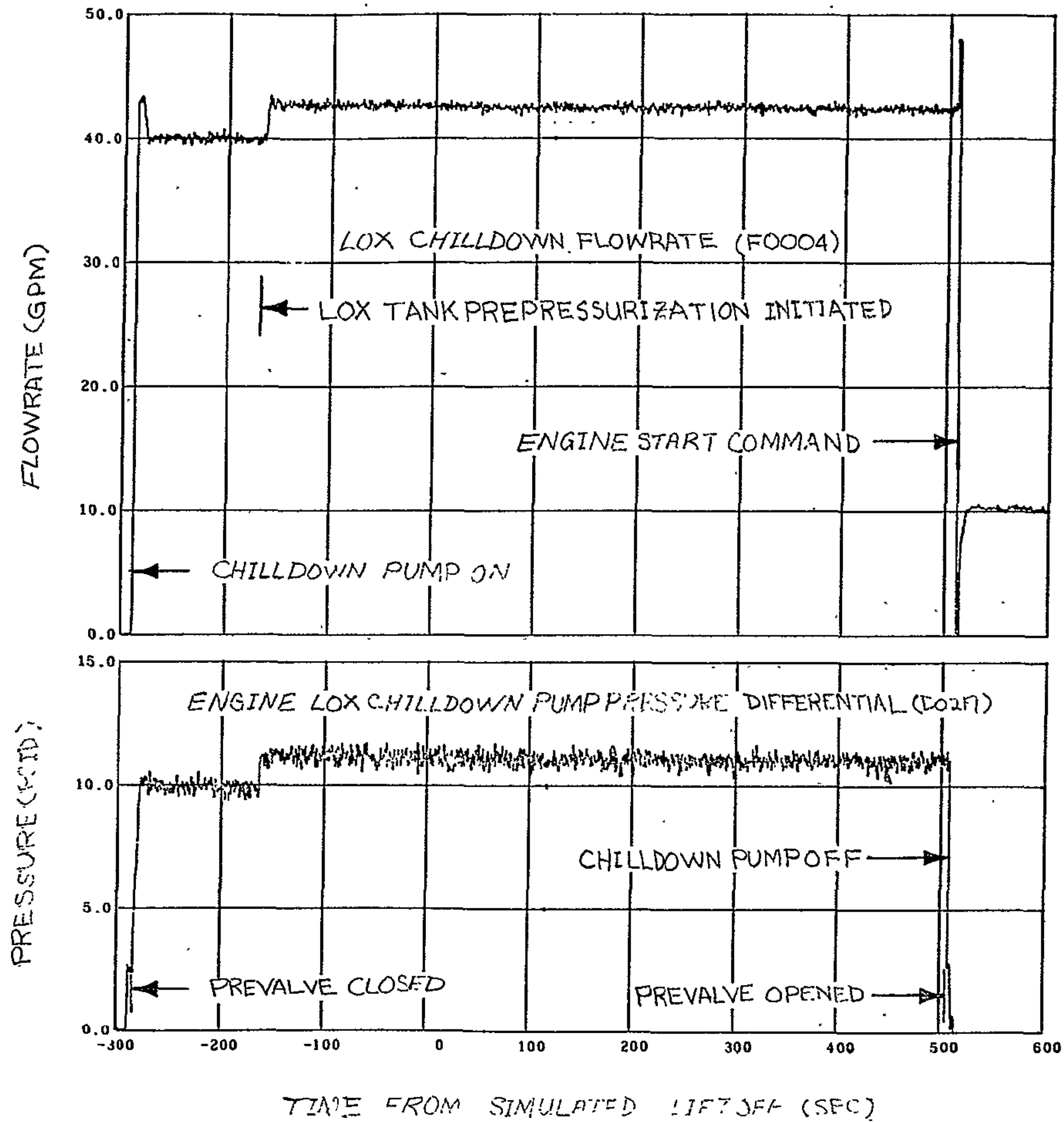


FIGURE 7-7. LOX PUMP CHILLDOWN (SHEET 1 OF 3)

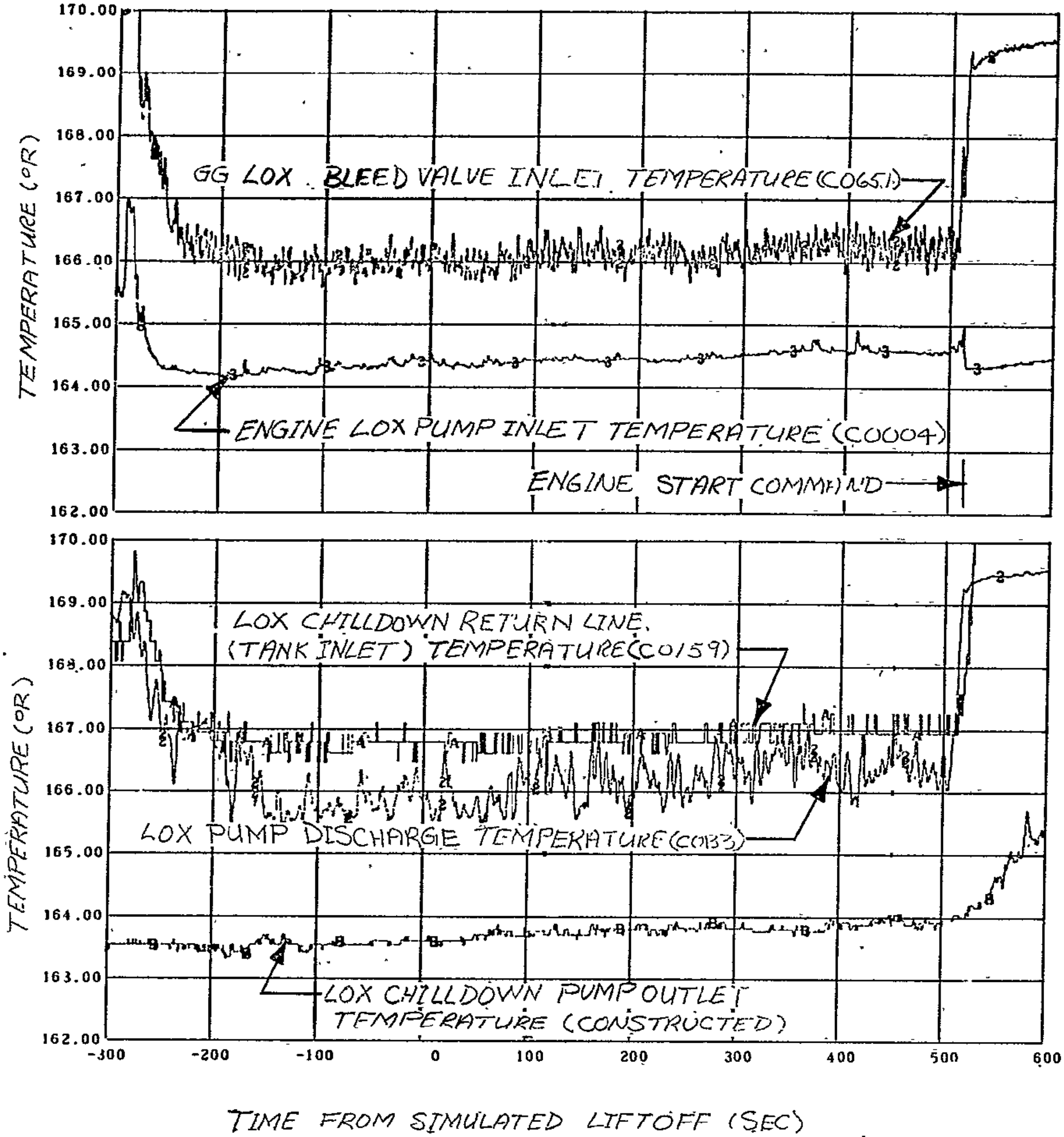


FIGURE 7-7. LOX PUMP CHILLDOWN (SHEET 2 OF 3)

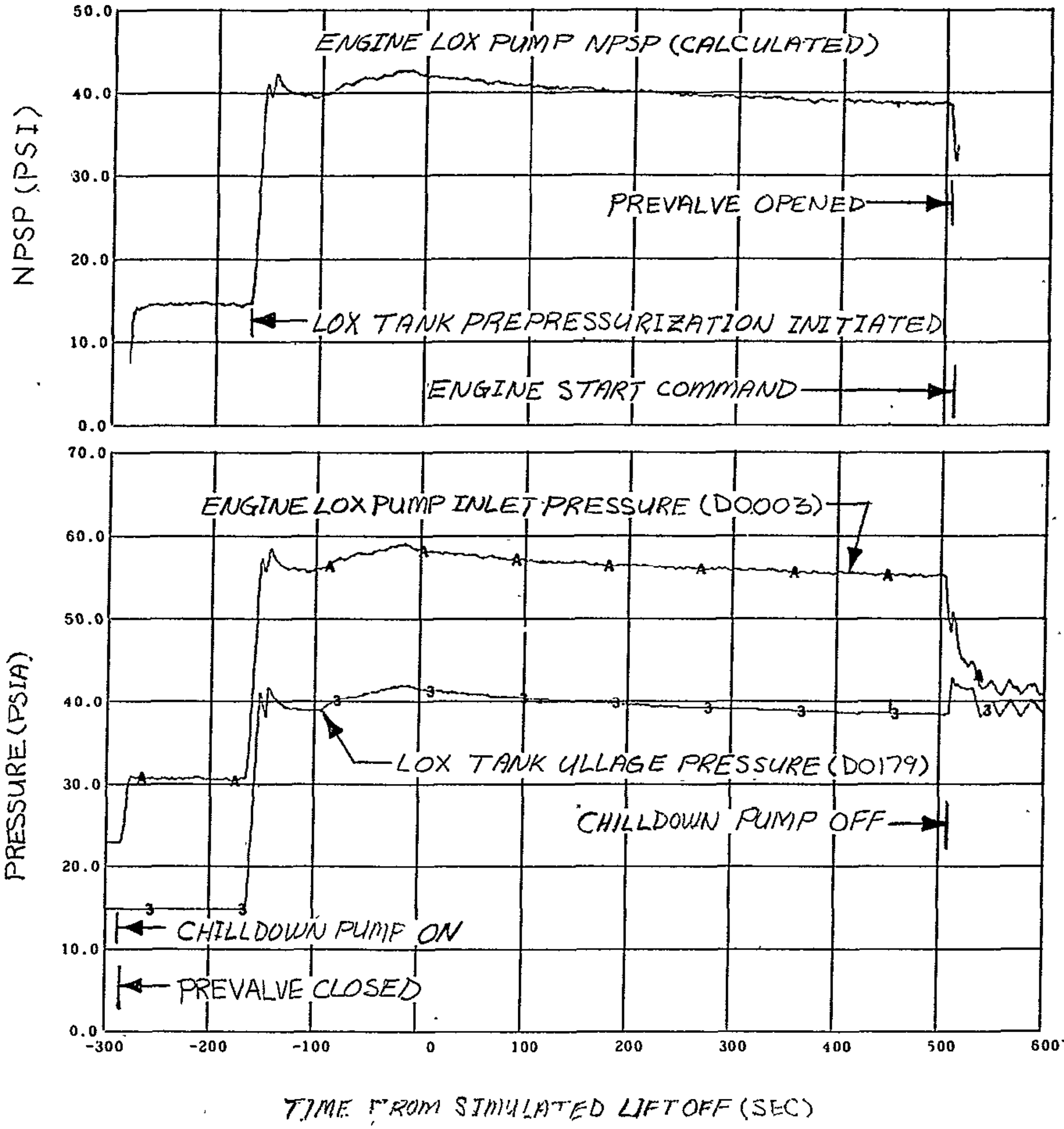


FIGURE 7-7. LOX PUMP CHILLDOWN (SHEET 3 OF 3)

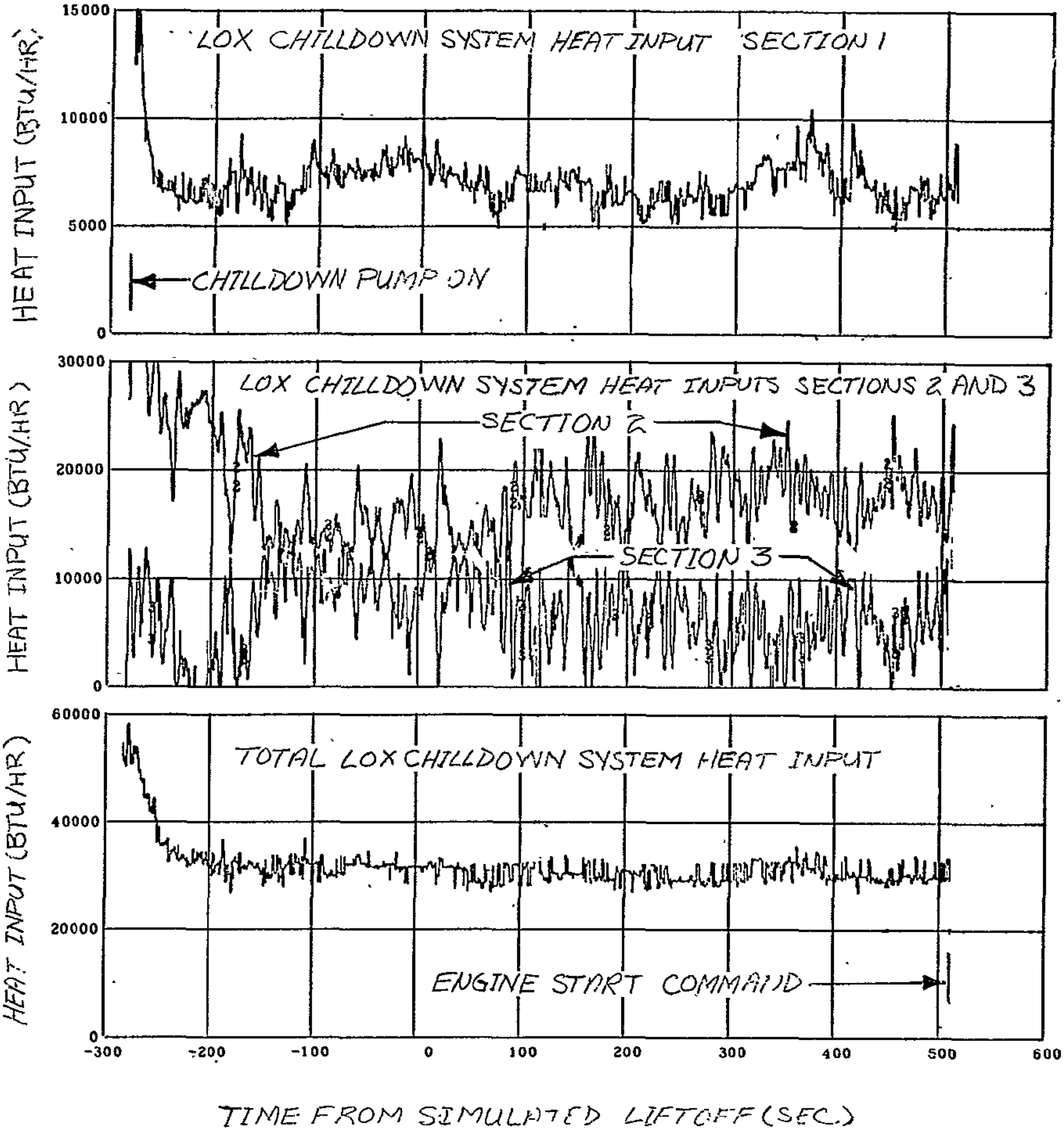


FIGURE 7-8. LOX PUMP CHILLDOWN CHARACTERISTICS

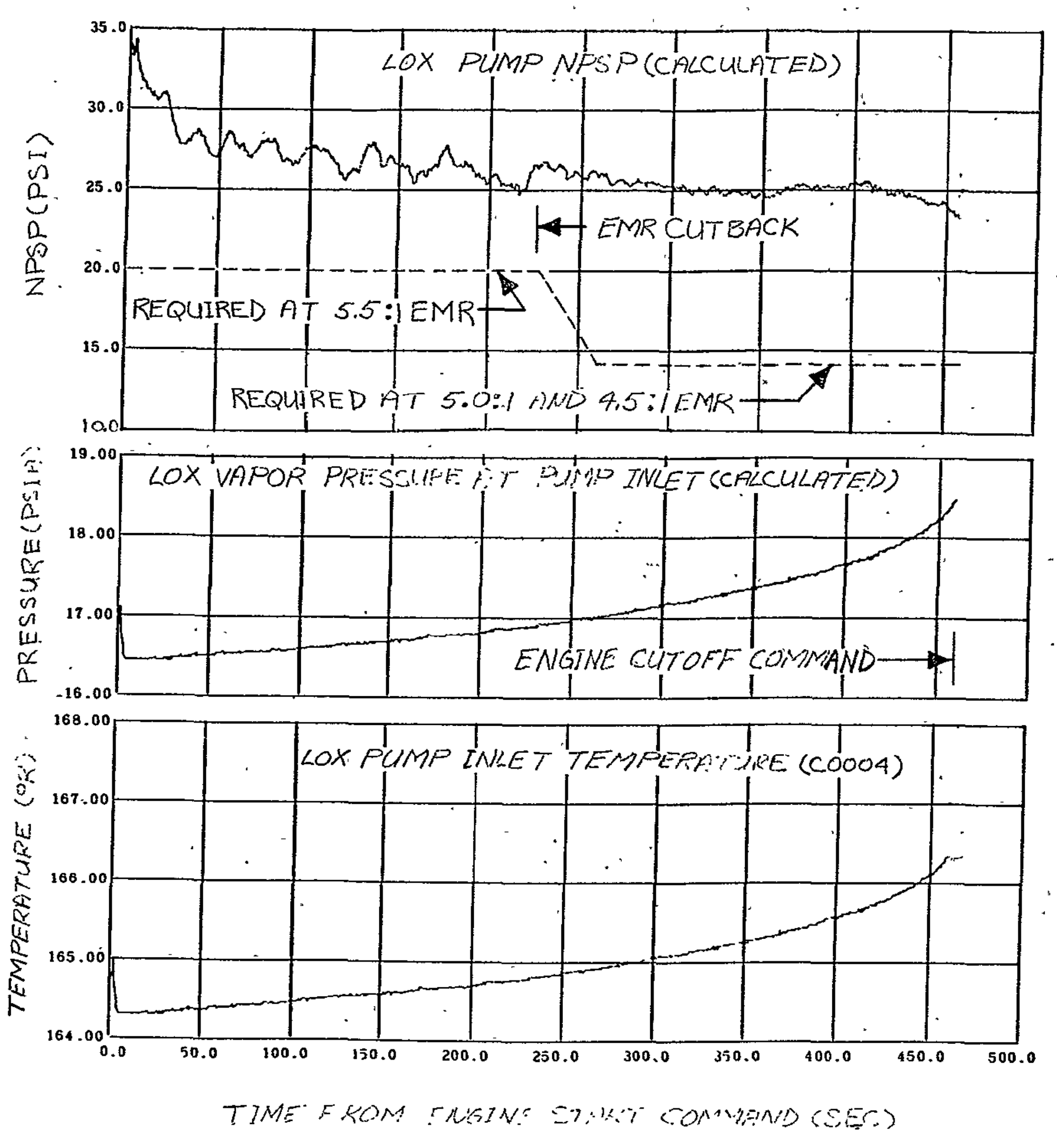


FIGURE 7-9. LOX PUMP INLET CONDITIONS (SHEET 1 OF 2)

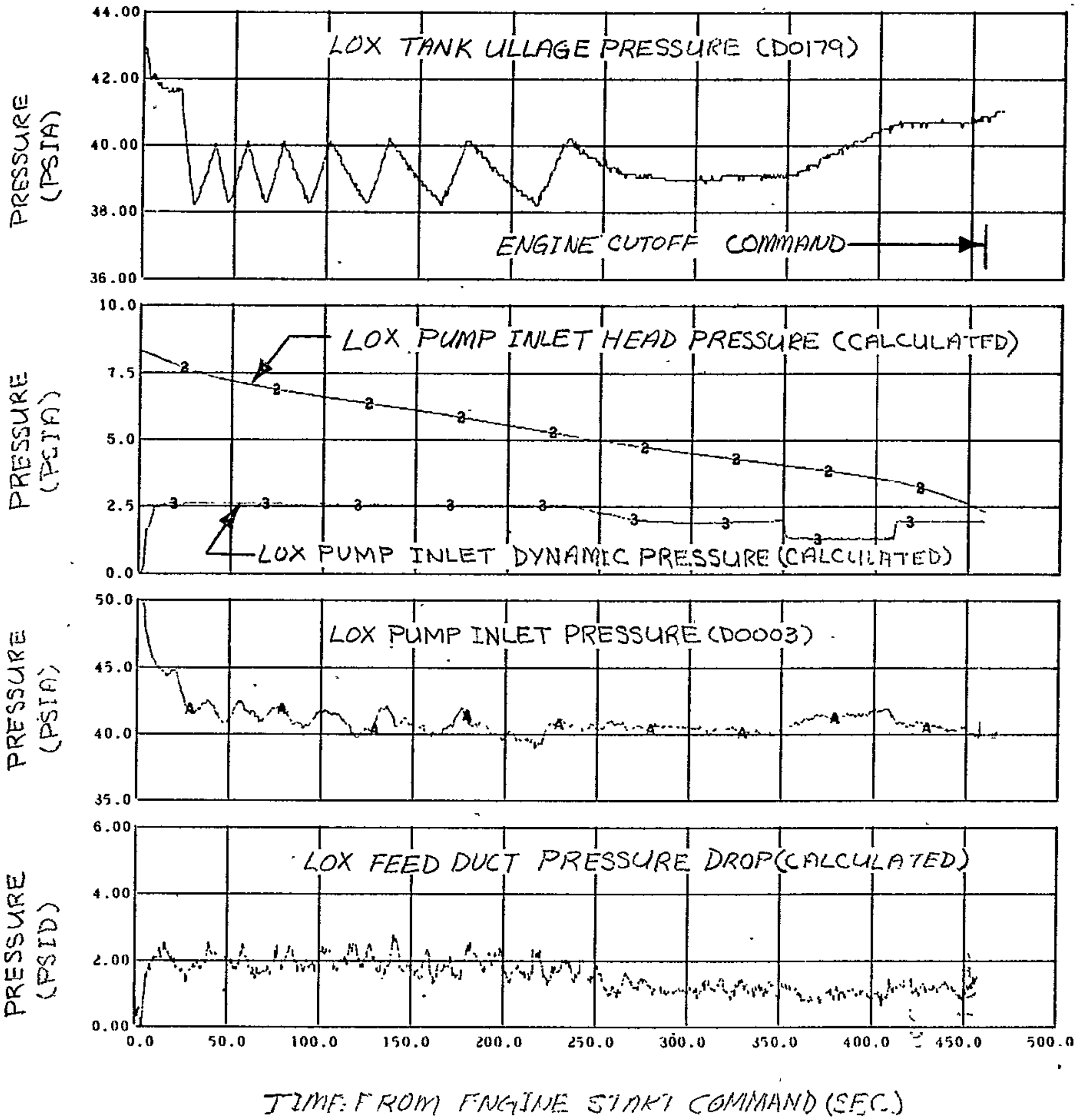


FIGURE 7-9. LOX PUMP INLET CONDITIONS (SHEET 2 OF 7)

180

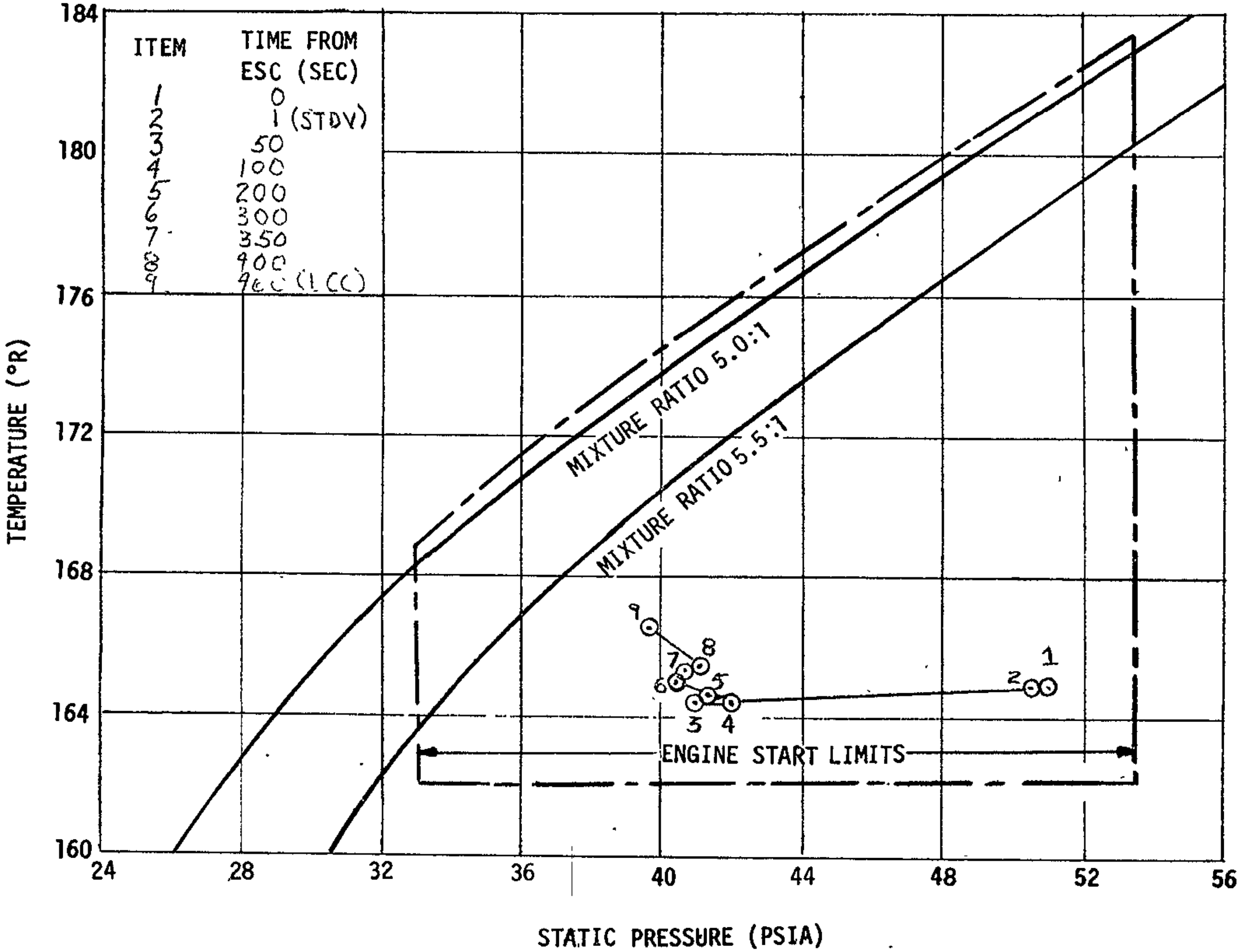


Figure 7-10. LOX Pump Inlet Conditions During Firing

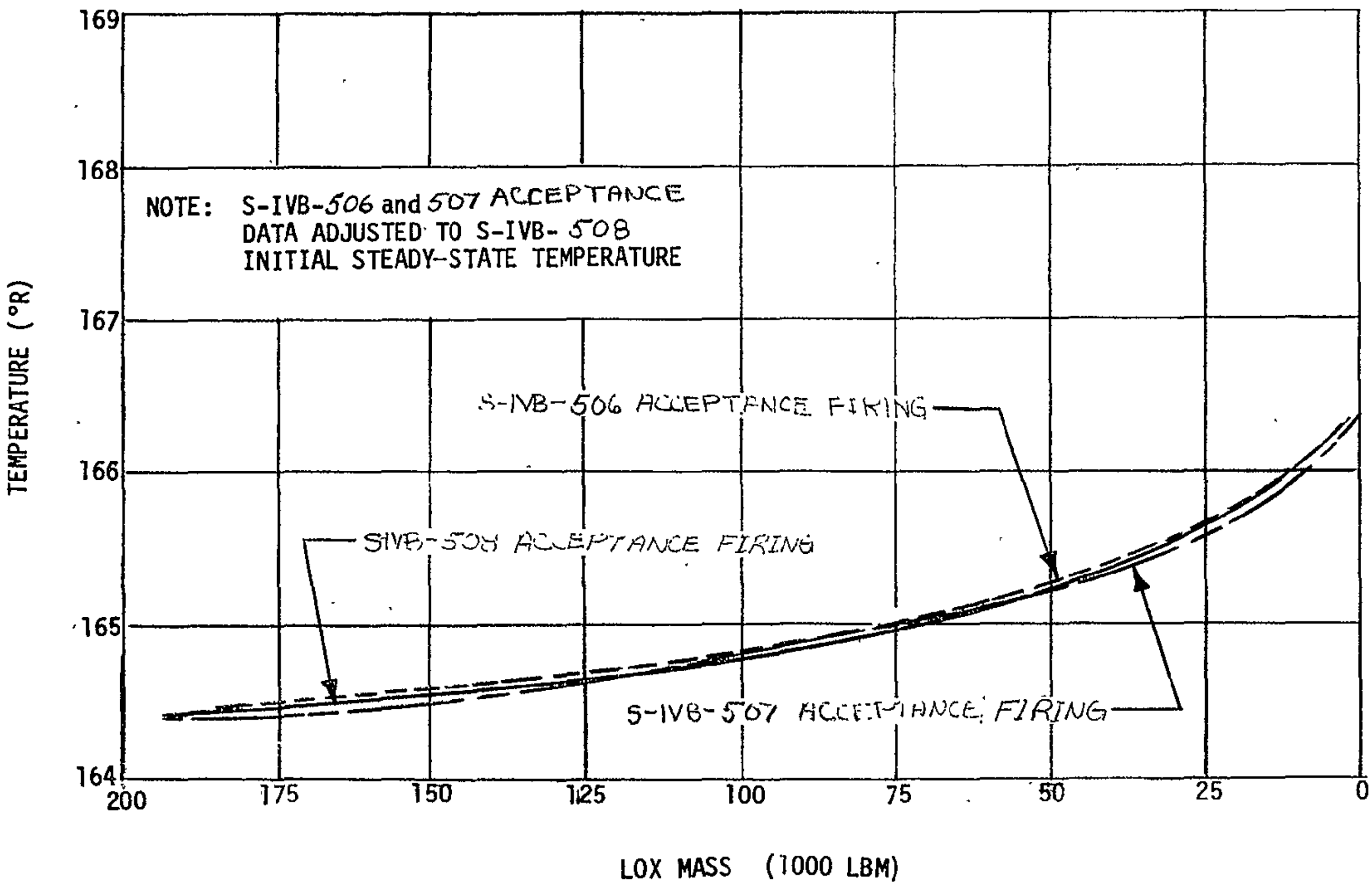


Figure 7-11, Effect of LOX Mass Level on LOX Pump Inlet Temperature

SECTION 8

FUEL SYSTEM

the firing because of bulk heating, step pressurization was initiated at ESC +410 seconds. This was coincident with the EMR being returned to 5.0:1 and resulted in another significant change in pressurization system performance.

The LH2 tank ullage pressure was above the 30.2 psia pressure switch pickup level throughout the firing. The vent and relief valve microswitch talkback indicated that the valves were partially open and venting from ESC +4 seconds to ESC +257 seconds and again subsequent to LH2 tank step pressurization during the period from ECC -44 seconds to engine cutoff command.

8.1.3 O2-H2 Burner Repressurization

The O2-H2 burner was utilized for LH2 tank repressurization. For the test, the tank was filled to a nominal second start level. Burner start command was followed by a 7.49-second lag before the initiation of repressurization in order to provide higher burner chamber pressure (and improved combustion stability) during the start transient. The LH2 tank conditions are shown in figure 8-3; significant data are compared to previous stage data in table 8-3. Additional, more detailed discussion is presented in section 10.

The LH2 tank ullage pressure rise rate was 20 percent higher than the theoretical rate of 3.16 psi/min that was based on a constant-Q burner, a constant helium flowrate, and an assumed constant burner helium inlet temperature of 40 deg R (the same reference conditions used for previous acceptance firing evaluations). During the S-IVB-508 burner operation, the actual total energy in the helium at the burner outlet to the LH2 tank was 25 percent higher than the theoretical total energy calculated by assuming the temperature of the helium at the burner inlet to be 40 deg R. The 25 percent increase was due to the ambient heating that occurs between the cold helium spheres and the O2-H2 burner inlet. This large amount of ambient heating is an expected condition during acceptance testing.

Under ideal conditions any heating above the reference should be reflected by a corresponding percentage increase in the pressurization rate above

8. FUEL SYSTEM

The fuel system performed as designed and supplied LH2 to the engine within the limits defined in the engine specification.

8.1 Pressurization Control

The LH2 tank pressurization system (figure 3-1) adequately controlled LH2 tank ullage pressure during prepressurization, throughout the firing, and during the repressurization periods.

8.1.1 Prepressurization

The LH2 tank was satisfactorily prepressurized with helium from ground support equipment (GSE) console B. Figure 8-1 presents the prepressurization data; table 8-1 compares the S-IVB-508 data with that from 507 and 506N stages. The rate of prepressurization was substantially slower on 508 than on 507 because the supply pressure, measurement D0792, was significantly lower (figure 8-1). Prepressurization was terminated by actuation of the control pressure switch at SLO -51.8 seconds. After prepressurization, the ullage pressure increased because of ambient heating until it reached a level of 32.3 psia. At this point the ullage pressure stabilized, apparently as a result of relief valve action, and remained essentially constant until engine start command.

8.1.2 Pressurization

During engine operation, the LH2 tank pressurization was satisfactorily accomplished by GH2 bleed from the J-2 engine (figure 3-1). The data are presented in figure 8-2 and compared with data from two previous acceptance firings in table 8-2.

In order to exercise all system components in both burn modes, control was transferred from the first burn pressurization mode to the second burn pressurization mode at ESC +350 seconds. Since the pressure switch range is the same for both modes (28 to 31 psia), system performance did not deviate because of the change to the second burn pressurization mode; however, a programmed cutback of engine mixture ratio to 4.5:1, which also occurred at ESC +350 seconds, did affect certain performance parameters. To preclude the possibility of loss of NPSP near the end of

the theoretical. The actual and theoretical values do not agree because the boundary conditions vary slightly and because LH2 boiloff does not actually terminate when pressurization is initiated.

8.1.4 Ambient Helium Repressurization

Although the S-IVB-508 stage is equipped with an O2-H2 burner, the ambient helium repressurization system was retained as a redundant system. It was tested prior to the 508 J-2 firing.

The LH2 tank was satisfactorily repressurized from the five ambient helium spheres. Data and performance levels are presented in figure 8-4 and compared to S-IVB-507 and 506N data in table 8-3.

8.2 LH2 Tank Vent and Relief Operations

The LH2 tank ullage pressure was maintained at an acceptable level throughout the acceptance firing.

8.2.1 LH2 Tank Vent and Relief Valve Performance

Performance of the LH2 tank vent and relief valve and the latching valve was satisfactory. The LH2 tank ullage pressure profile indicates that one or both of the valves relieved from shortly after simulated liftoff to EMR cutback; however, the valve microswitch talkbacks indicated the valves were only feathering intermittently. Both valves relieved shortly after LH2 tank step pressurization, and valve talkbacks indicated that the valves remained partially open until after engine cutoff command.

8.2.2 Vent Operations During Simulated Coast

The continuous vent system (CVS) was operated for approximately 37 minutes prior to O2-H2 burner repressurization. Both the CVS nozzles and the nonpropulsive vent (NPV) orifices were removed, and a manifold system conducted the vented GH2 to the facility burn pond. At the LH2 tank ullage pressures maintained during the period, the flow of GH2 through the manifold (to atmospheric back pressure) was unchoked; however, choked flow at the vent exits will occur during actual orbital coast conditions. Due to the common manifold system, venting through either the CVS or NPV is reflected in the pressure data from both systems (figure 8-5).

Continuous venting was initiated by opening the relief override valve and allowing the continuous vent regulator (CVR) to open. After CVS initiation the ullage pressure decayed from 31.7 to 27.5 psia in 49 seconds, yielding a pressure decay rate of 5.1 psi/min. This is consistent with the decay rates of 4.9 and 5.9 psi/min noted on the 507 and 506N stages, respectively. At 49 seconds after CVS initiation the CVR was closed. The CVS bypass orifice was opened at CVS initiation plus 61 seconds, and the CVR was opened at CVS initiation plus 109 seconds. A nominal CVS regulation level of 20.5 psia was established.

8.3 LH2 Pump Chilldown

The LH2 pump chilldown system performed adequately. At engine start command the net positive suction pressure (NPSP) at the LH2 pump inlet was above the 4.5 psi required. The chilldown system data are presented in figures 8-6 and 8-7. The S-IVB-508 acceptance test data are compared in table 8-4 with data from two previous acceptance firings.

The chilldown system operation was initiated at SLO -298.7 seconds. System performance levels compared well with those of previous S-IVB/V acceptance firings. During unpressurized chilldown, the liquid in the system was subcooled to a point between the engine pump inlet and the chilldown system return line; the system became entirely subcooled during prepressurization. The chilldown shutoff valve was left open until shortly before engine cutoff command (ECC -38 seconds).

For the calculation of heat input to section 1 (tank to pump inlet) of the LH2 chilldown system, the reference temperature is the chilldown pump discharge temperature (C0157). Since this measurement was not installed on S-IVB-504N and subsequent stages, the LH2 bulk temperature (C0052) plus a 0.3 degree R bias was substituted. The bias was established from previous acceptance firing data.

8.4 Engine LH2 Supply

The LH2 supply system (figure 3-1) delivered the necessary quantity of LH2 to the engine pump inlet during engine firing and maintained the

pressure and temperature conditions within a range that provided an LH2 pump NPSP above the minimum requirements. The data and the calculated performance are presented in figure 8-8. Table 8-5 compares the S-IVB-508 stage recorded data and calculated performance data with that from previous S-IVB acceptance firings.

During engine operation, the LH2 pump inlet temperature and pressure were very near the predicted values. The LH2 pump inlet temperature and pressure at selected times during engine operation were plotted in the engine LH2 pump operating region (figure 8-9) and showed that the engine inlet conditions were met satisfactorily throughout engine operation.

Figure 8-10 is a plot of the pump inlet temperature as a function of the propellant mass remaining in the LH2 tank and includes S-IVB-507 and 506N data comparisons. The previous test data have been biased to the LH2 pump inlet temperature observed at engine start command of S-IVB-508 acceptance firing to correct for instrument error, different heating during pressurization, and other test-to-test variations.

During the engine cutoff transient, a high pressure spike occurred in the engine fuel feed duct. As a result, the pump inlet pressure flight transducer (D0002) failed. Post-test inspection disclosed that the lower fuel duct vacuum annulus contained approximately 72 percent hydrogen and 24 percent helium. Further investigation after the upper and lower ducts had been replaced revealed two cracks in the middle bellows of the lower duct.

TABLE 8-1

LH2 TANK PREPRESSURIZATION DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Prepressurization duration (sec)	42.4	31.8	50.5
Helium mass added (lbm)	26.6	25.7	20.2
Ullage pressure			
At prepressurization initiation (sec)	15.2	15.2	15.4
At prepressurization termination (sec)	31.0	30.3	30.2
At simulated liftoff (psia)	31.5	31.5	31.0
At engine start command (psia)	32.3	31.7	32.0
Rate of increase after prepressurization (psi/min)	0.8	1.2	0.9
Events (sec from simulated liftoff)			
Prepressurization initiation	-94.2	-94.1	-94.7
Prepressurization termination	-51.8	-62.3	-44.2
Engine start command	511.7	511.7	511.4

TABLE 8-2

LH2 TANK PRESSURIZATION DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Pressure switch setting			
First burn			
Lower (psia)	28.6	28.2	28.3
Upper (psia)	30.7	30.3	30.7
Second burn			
Lower (psia)	28.3	28.4	28.3
Upper (psia)	30.1	30.6	30.5
Ullage pressure			
At engine start command (psia)	32.3	31.7	32.0
At step pressurization (psia)	32.2	31.7	31.9
At engine cutoff command (psia)	32.9	32.1	32.7
GH2 pressurant flowrate			
Overcontrol--high EMR (lbm/sec)	--	--	--
Overcontrol--low EMR (lbm/sec)	--	--	--
Undercontrol--high EMR (lbm/sec)	0.70	0.63	0.63
Undercontrol--low EMR (lbm/sec)	0.66	0.61	0.60
Step	1.07	1.09	1.03
Total GH2 added (lbm)	328	281	290
Events (sec from simulated liftoff)			
Second burn mode initiation	862	712	712
Step pressurization initiation	922	921	921

TABLE 8-3

LH2 TANK REPRESSURIZATION DATA

Parameter	S-IVB-508		S-IVB-507		S-IVB-506N	
	Ambient	Burner	Ambient	Burner	Ambient	Burner
Repressurization duration (sec)	25	175*	28.9	151*	40	147*
Ullage volume (cu ft)	4,663	4,697	4,519	4,559	4,720	4,880
Ullage pressure						
At repressurization initiation (psia)	22.0	19.3	21.4	20.0	21.0	19.6
At repressurization termination (psia)	30.3	30.3	30.3	30.3	30.0	30.2
Rise rate (psi/min)	19.8	3.78	18.4	4.10	13.5	4.30
Repressurization helium usage (lbm)	20.5	20.1	22.5**	18.1	24.5**	16.5

* Does not include the lag in repressurization initiation following burner start command.

** These are not the values appearing in previous acceptance test reports. They represent the improved computational method effective with S-IVB-508.

TABLE 8-4

LH2 RECIRCULATION CHILLDOWN DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
NPSP			
At engine start command (psi)	8.9	13.3	8.8
Minimum required at start (psi)	4.5	4.5	4.5
Maximum during chilldown (psi)	18.9	21.0	19.2
Average flow coefficient (sec^2/in^2ft^3)	17.6	18.1	18.1
Fuel quality in sections* 2 and 3 (lb gas/lb mixture)			
Maximum--unpressurized chilldown	0.028	0.014	0.027
At prepressurization initiation	0.024	0.011	0.023
Fuel pump inlet conditions			
Static pressure at start (psia)	33.0	33.5	33.6
Temperature at start (deg R)	39.4	38.5	39.9
Amount of subcooling at start (deg R)	2.1	3.6	2.3
Heat absorption rate			
Unpressurized chilldown			
Section* 1 (Btu/hr)	20,500	10,000	20,000
Sections* 2 and 3 (Btu/hr)	18,500	18,000	17,500
Total (Btu/hr)	39,000	28,000	37,500
Pressurized chilldown			
Section* 1 (Btu/hr)	17,500	9,000	18,000
Section* 2 (Btu/hr)	12,500	12,000	8,500
Section* 3 (Btu/hr)	15,000	18,000	18,000
Total (Btu/hr)	45,000	39,000	44,500

* Section 1 is tank to pump inlet; section 2 is pump inlet to bleed valve; section 3 is bleed valve to tank.

Table 8-4 (Continued)

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Chilldown flowrate			
Unpressurized (gpm)	107	120	108
Pressurized (gpm)	138	140	137
Chilldown pump pressure differential			
Unpressurized (psi)	8.9	8.7	9.4
Pressurized (psi)	7.2	7.8	7.75
Events (sec from simulated liftoff)			
Chilldown initiated	-298.7	-298.6	-299.4
Prevalve closed	-283.3	-283.2	-283.9
Prepressurization	-94.2	-94.1	-94.7
Prevalve opened	510.1	510.2	509.7
Chilldown pump off	511.1	511.2	510.7
Engine start command	511.7	511.7	511.4
Chilldown shutoff valve closed	922.2	922.2	921.8

TABLE 8-5

LH2 PUMP INLET CONDITION DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Pump inlet conditions			
Static pressure at engine start command (psia)	33.0	33.5	33.6
Static pressure at engine cutoff command (psia)	30.2	31.7	31.1
Temperature at engine start command (deg R)	39.4	38.5	39.9
Temperature at engine cutoff command (deg R)	39.9	39.0	39.6
NPSP requirements at pump interface			
Minimum at engine start command (psi)	4.5	4.5	4.5
At high EMR (psi)	5.3	5.3	5.3
After EMR cutback (psi)	4.9	4.9	4.9
NPSP available at pump interface			
At engine start command (psi)	8.9	13.3	8.8
Maximum (psi)	16.3	15.9	15.1
Minimum (psi)	10.2	11.0	9.5
At engine cutoff command (psi)	11.2	11.0	10.0
LH2 suction duct			
At high EMR			
Pressure drop (psi)	0.6	0.3	0.5
Flowrate (lbm/sec)	82	85	83
After EMR cutback			
Pressure drop (psi)	0.5	0.5	0.4
Flowrate (lbm/sec)	79	84	80

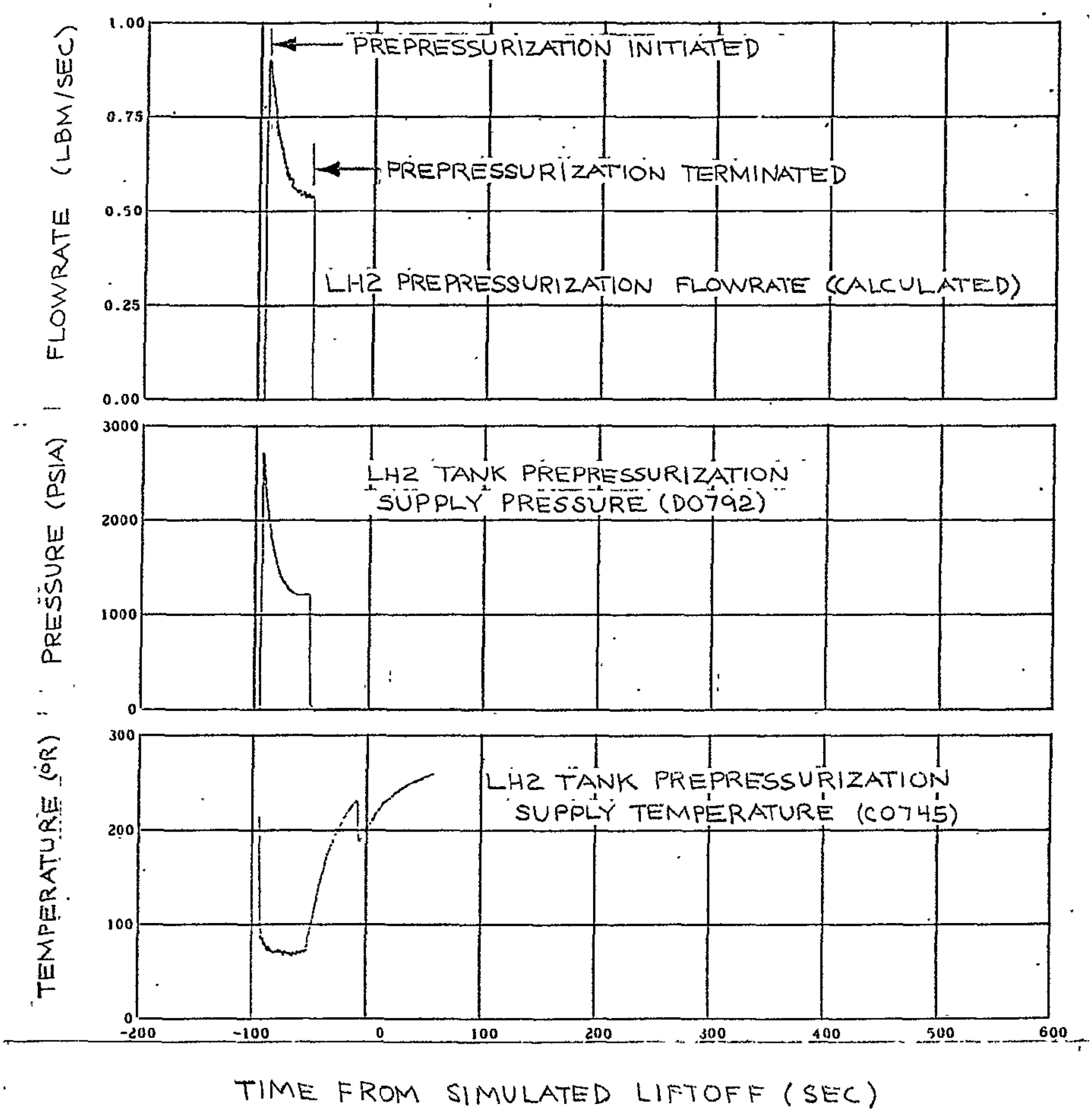


FIGURE 8-1. - LH2 TANK PREPRESSURIZATION SYSTEM PERFORMANCE (SHEET 1 OF 2)

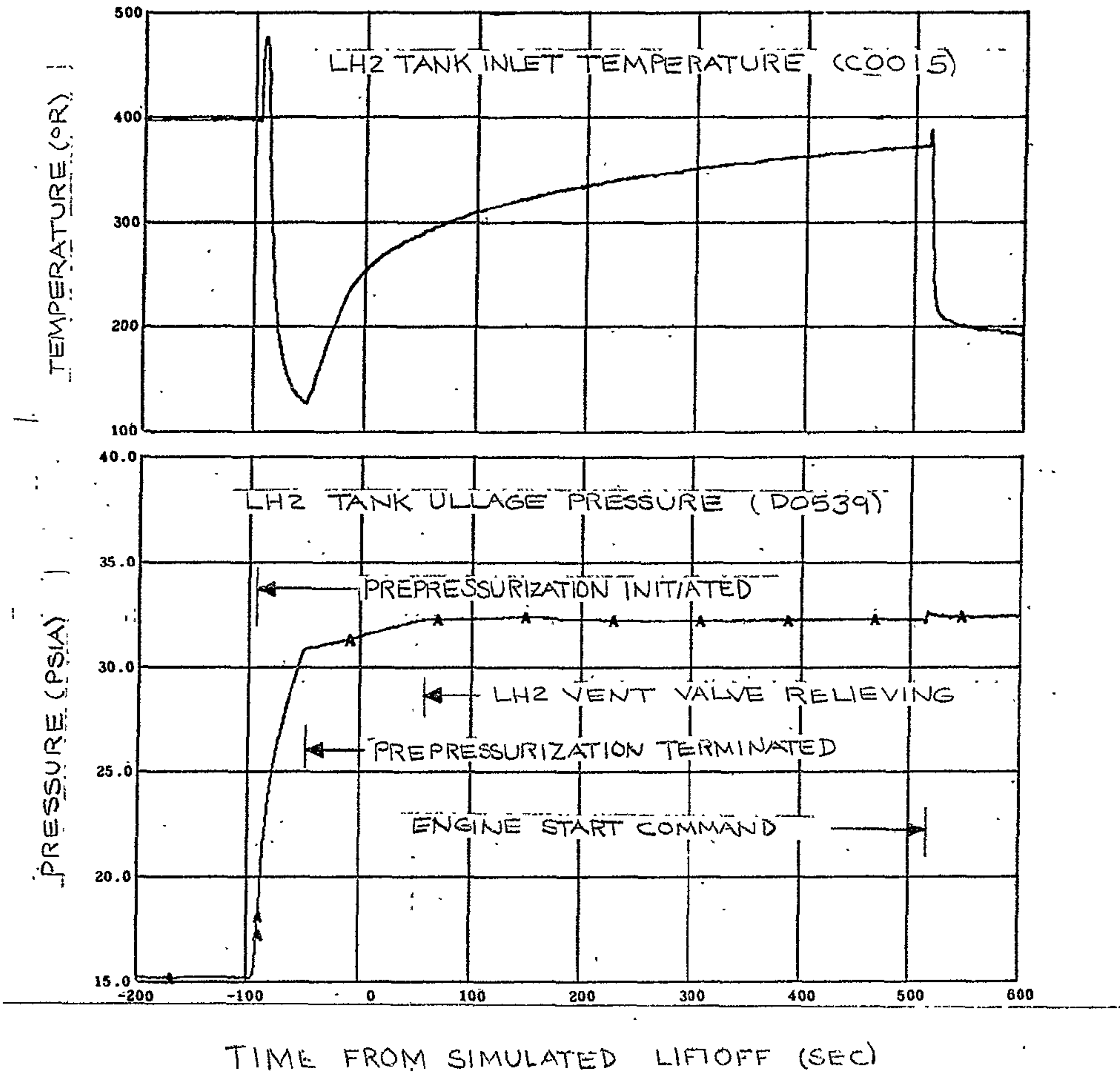


FIGURE 8-1. LH2 TANK PREPRESSURIZATION SYSTEM PERFORMANCE (SHEET 2 OF 2)

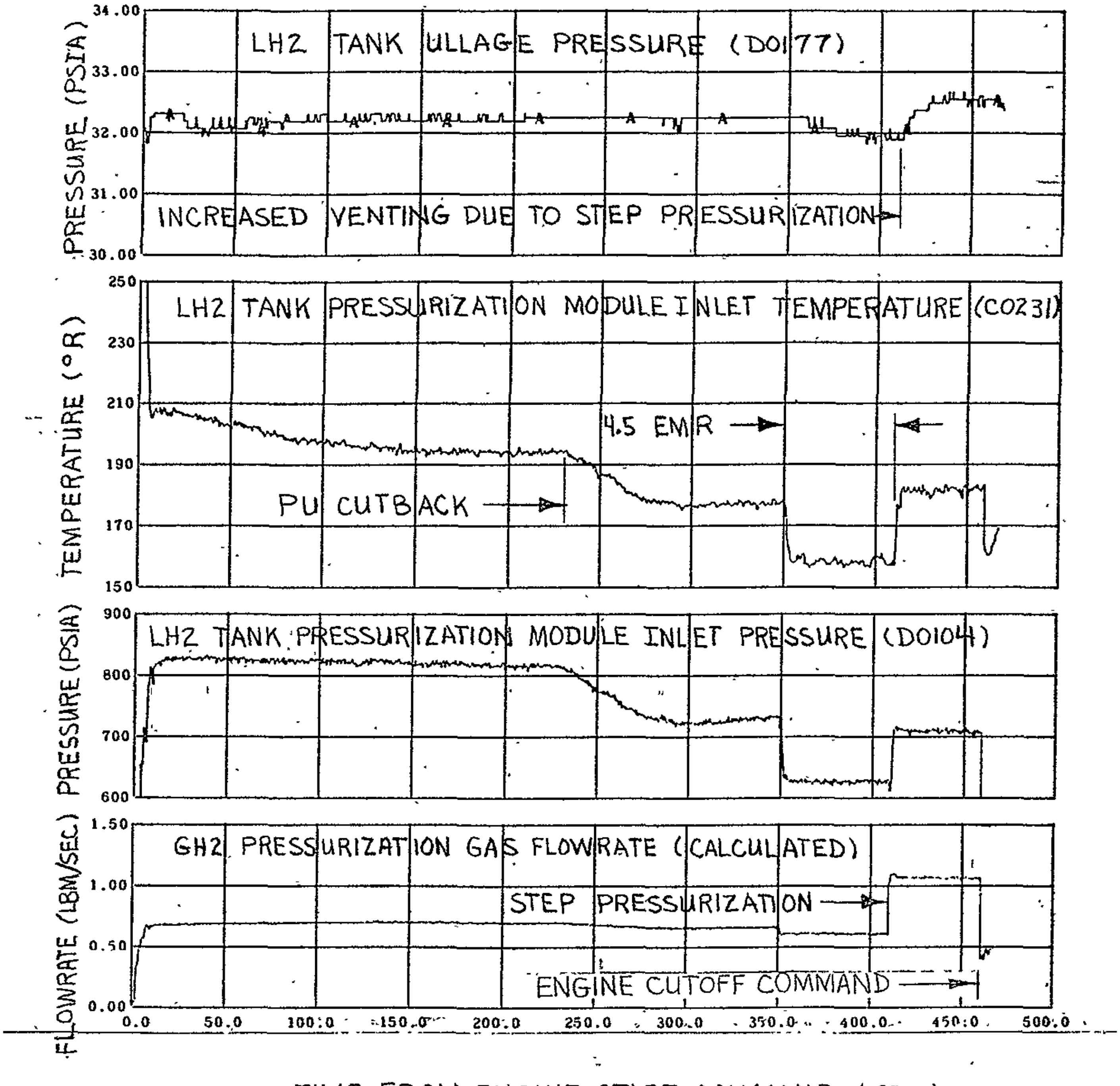


FIGURE 8-2. LH2 TANK PRESSURIZATION SYSTEM PERFORMANCE (SHEET 1 OF 2)

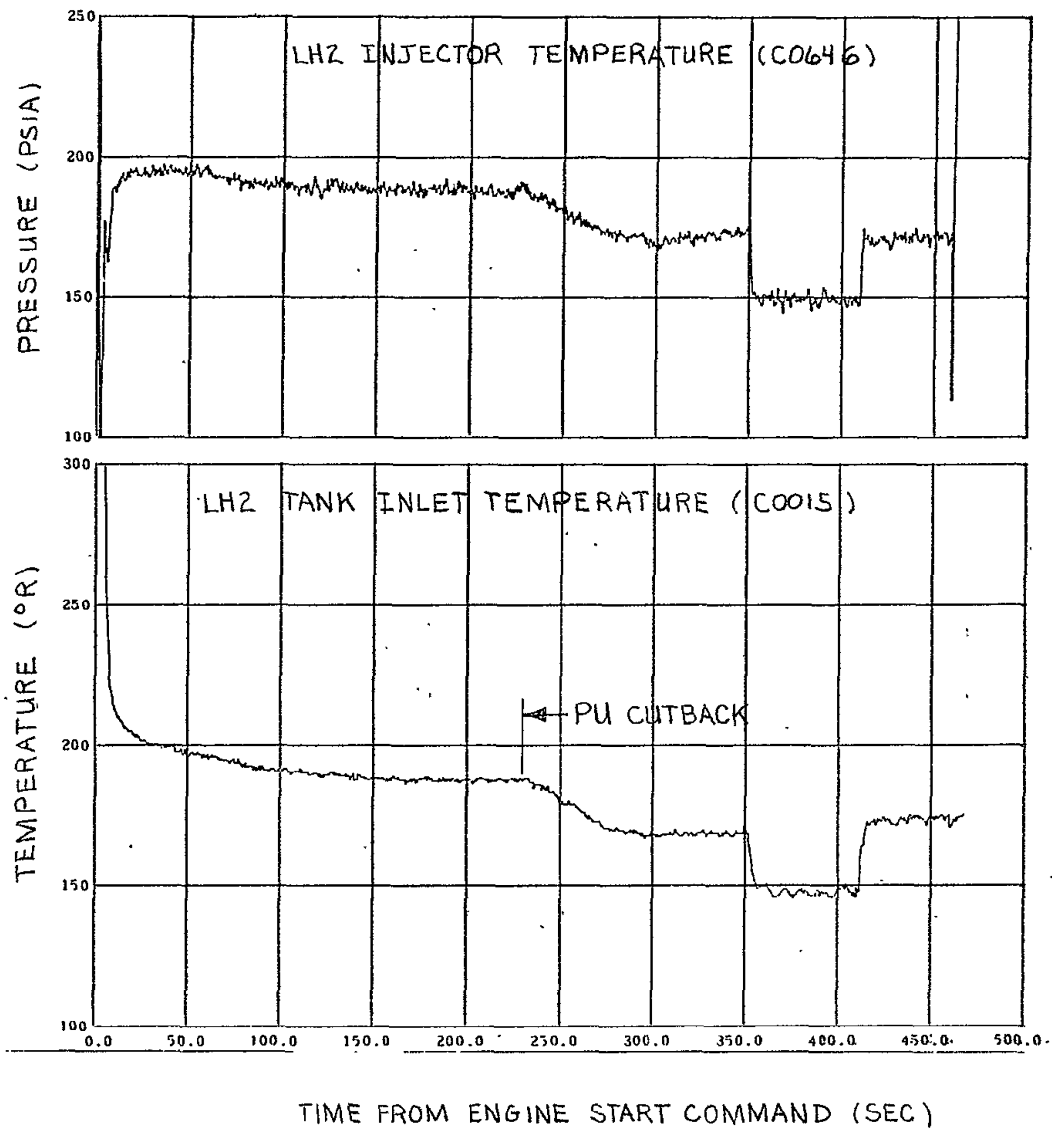


FIGURE 8-2. LH2 TANK PRESSURIZATION SYSTEM PERFORMANCE (SHEET 2 OF 2)

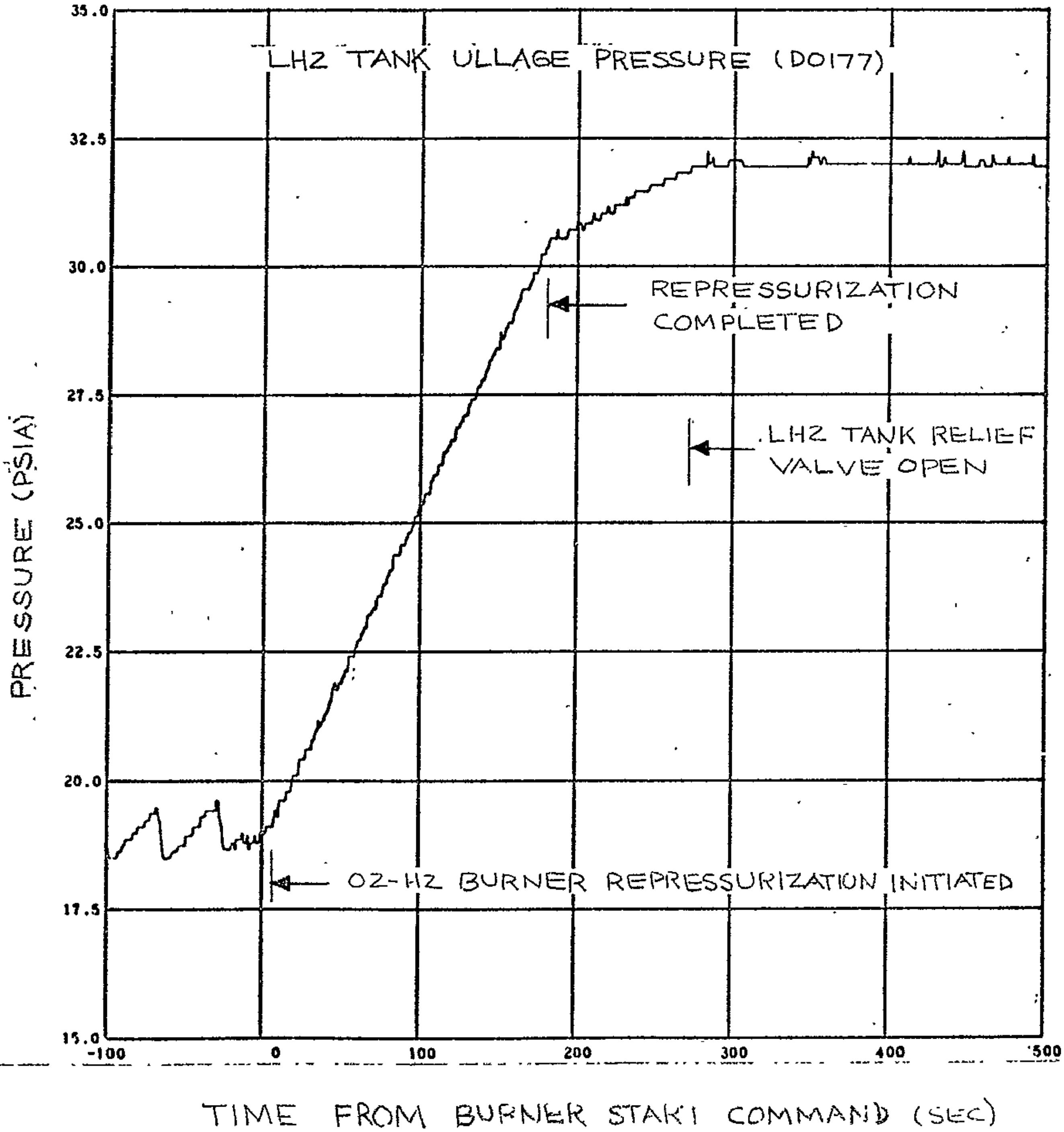


FIGURE. 8-3. LH2 TANK PRESSURE DURING O2-H2 BURNER REPRESSURIZATION

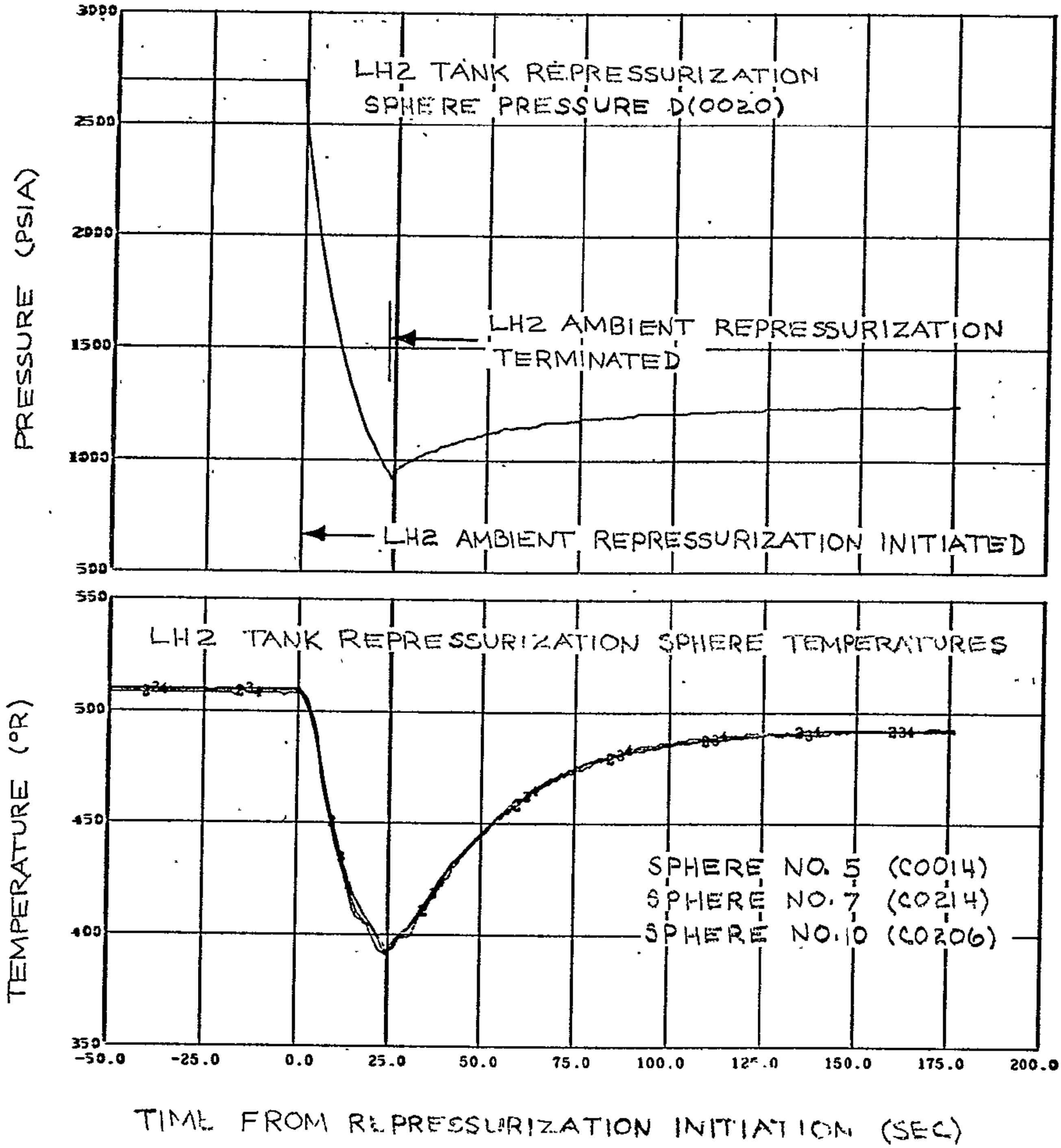


FIGURE 8-4. LH2 AMBIENT HELIUM REPRESSURIZATION SYSTEM PERFORMANCE (SHEET 1 OF 2)

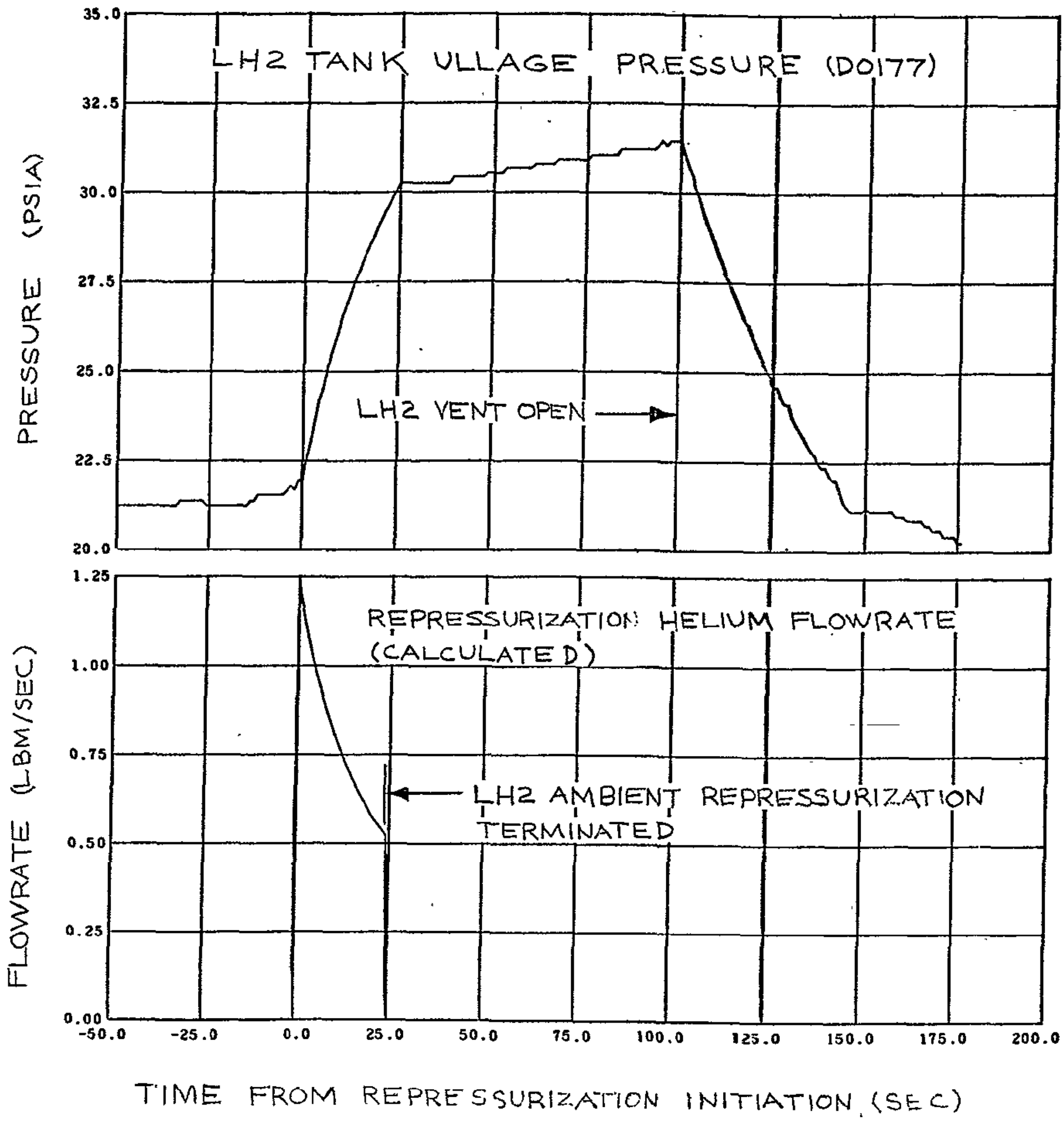


FIGURE 8-4. LH2 AMBIENT HELIUM REPRESSURIZATION SYSTEM PERFORMANCE (SHEET [illegible] OF [illegible])

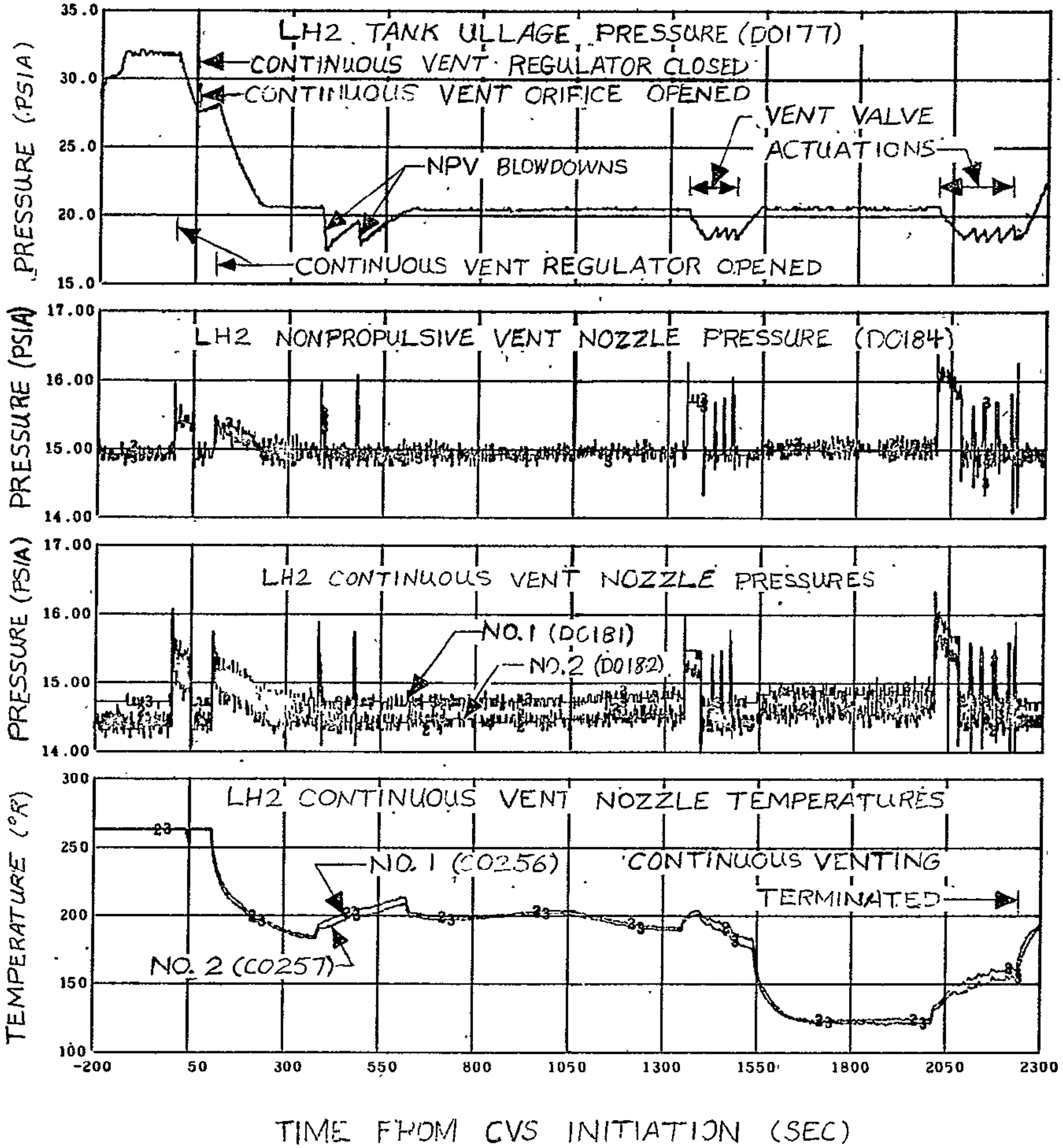


FIGURE 8-5. LH2 TANK VENTING SYSTEM OPERATION

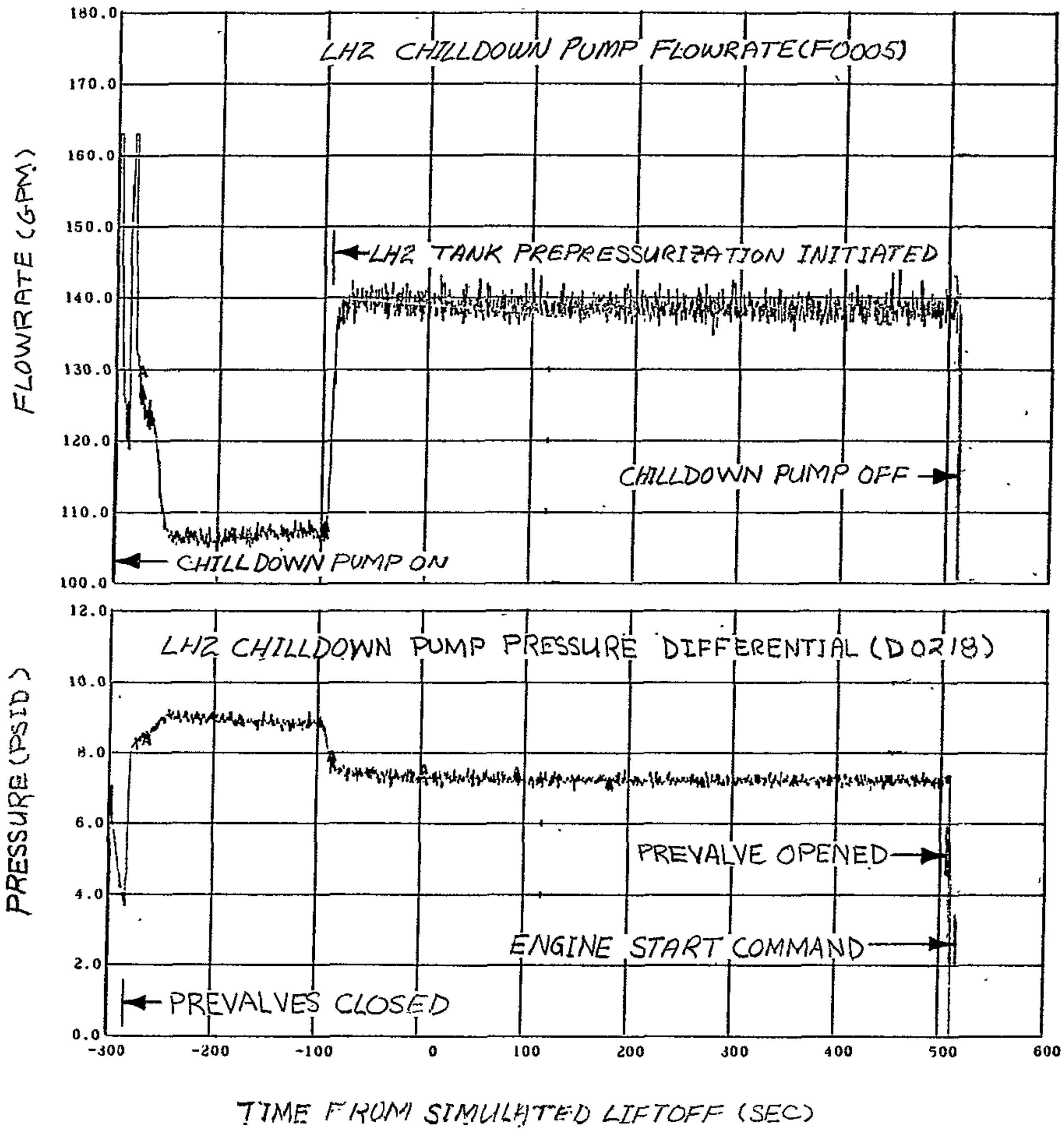


FIGURE 8-6. LH2 PUMP CHILLDOWN (SHEET 1 OF 3)

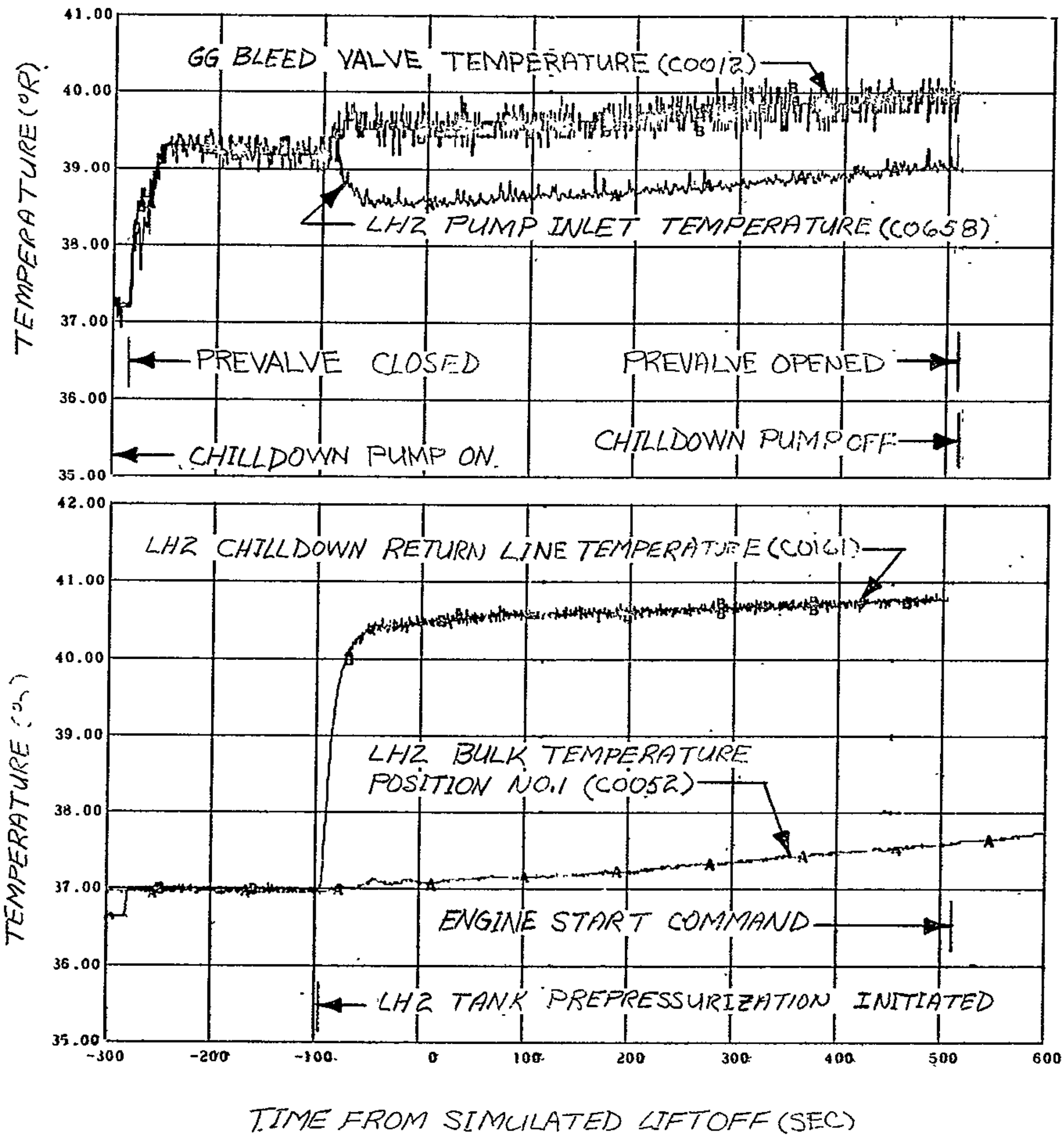


FIGURE 8-6. LH2 PUMP CHILLDOWN (SHEET 2 OF 3)

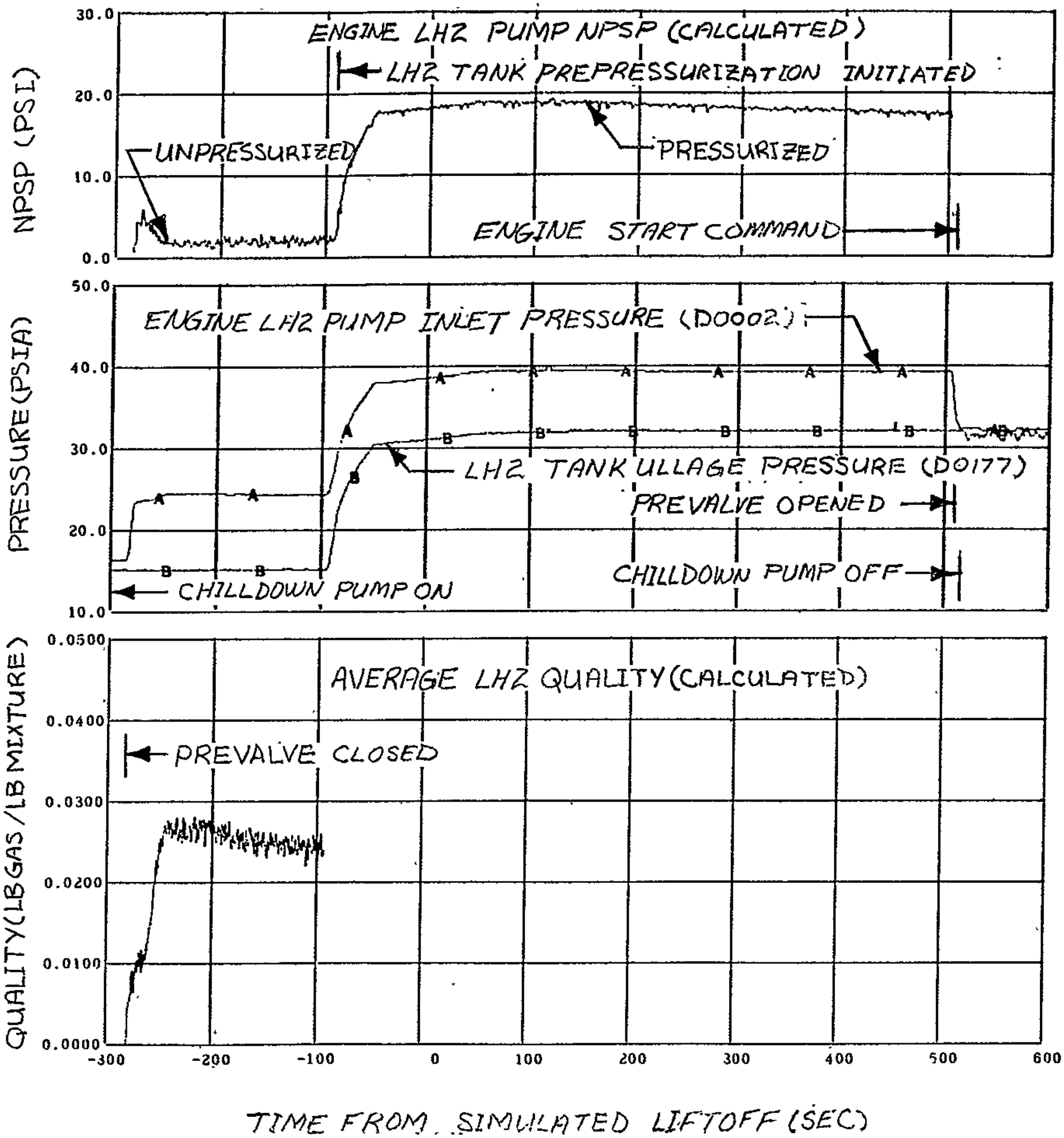


FIGURE 8-6. LH2 PUMP CHILLDOWN (SHEET 3 OF 3)

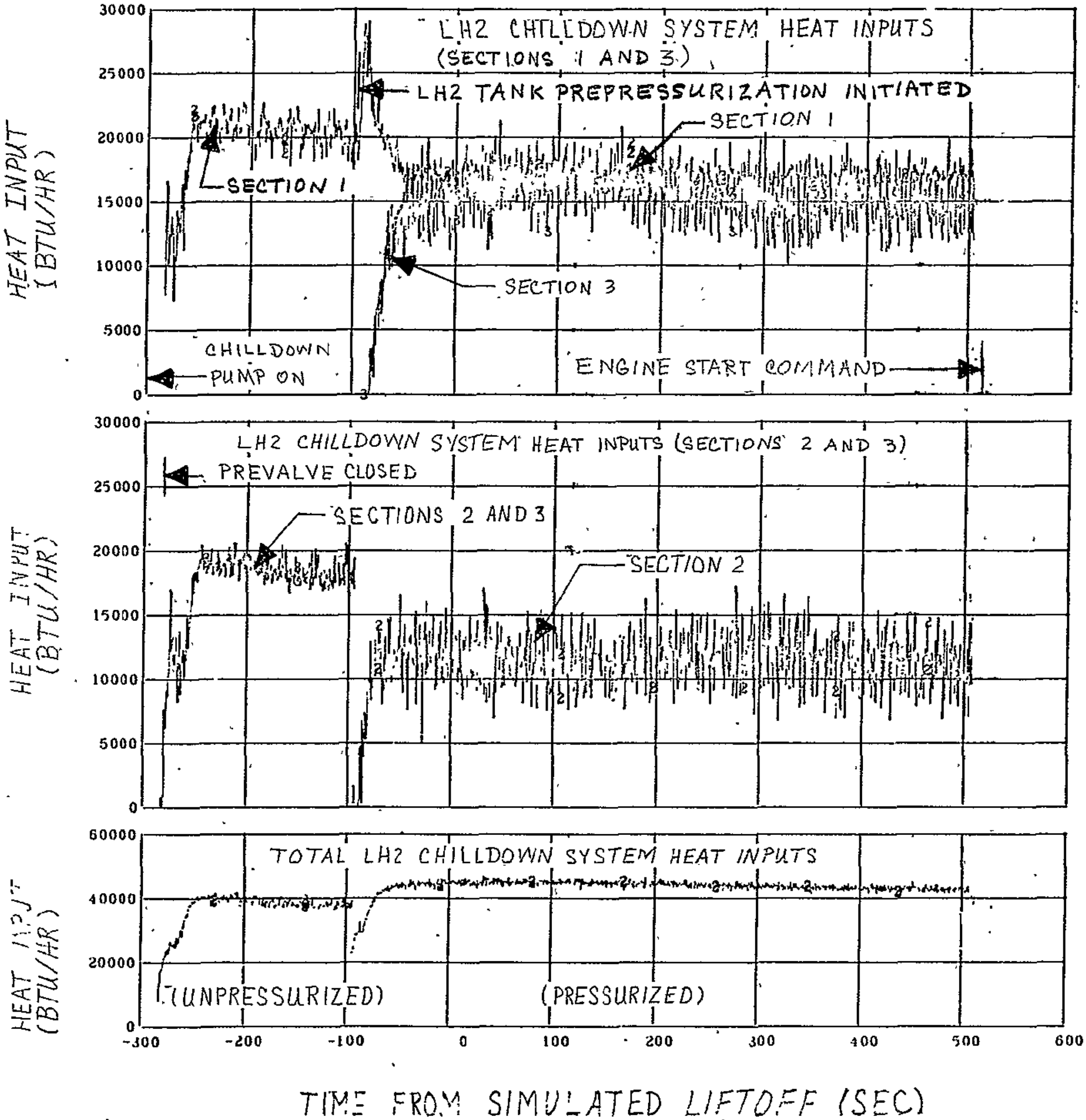


FIGURE 8-7. LH2 PUMP CHILLDOWN CHARACTERISTICS

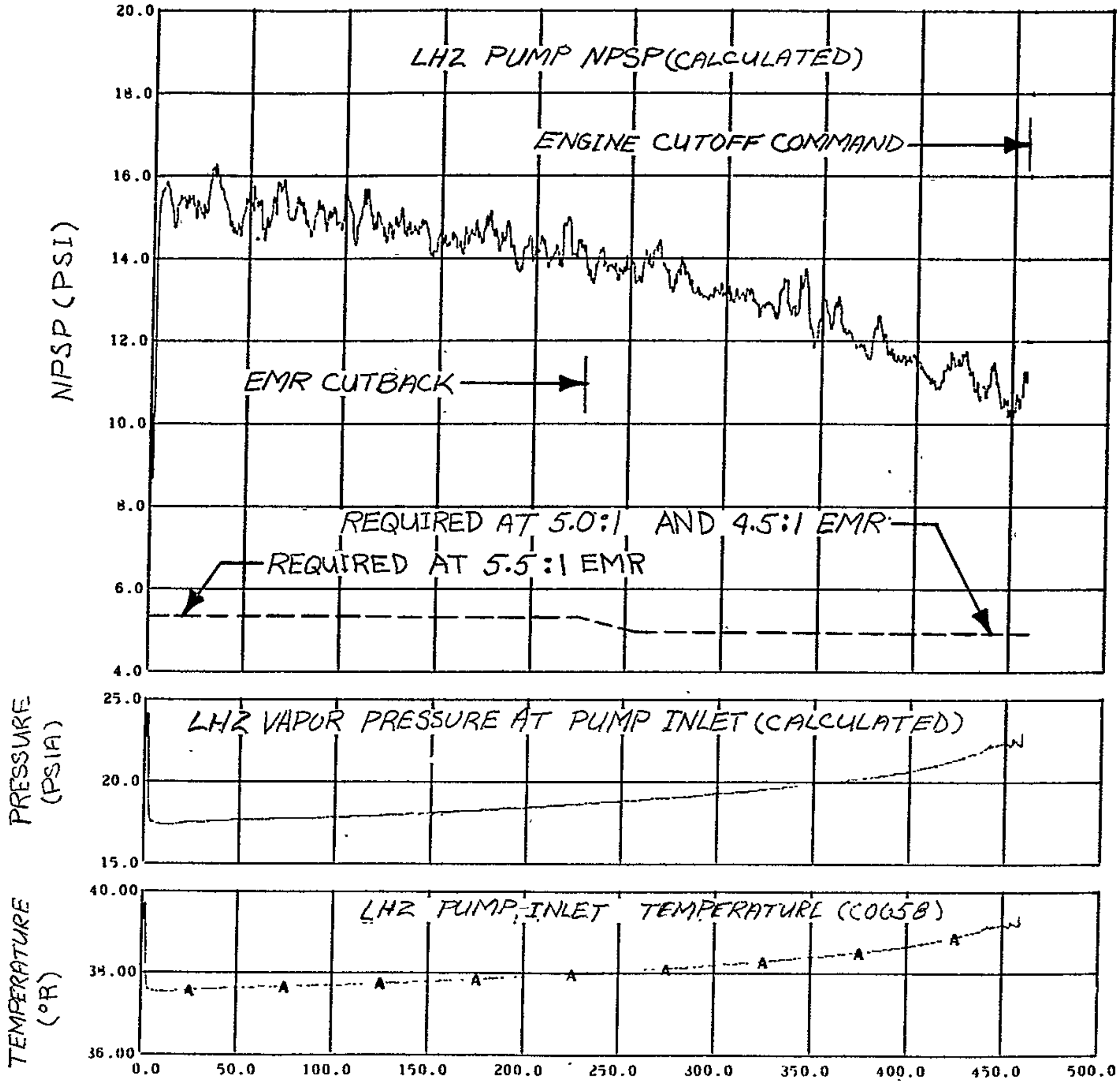


FIGURE 8-8. LH2 PUMP INLET CONDITIONS (SHEET 1 OF 2)

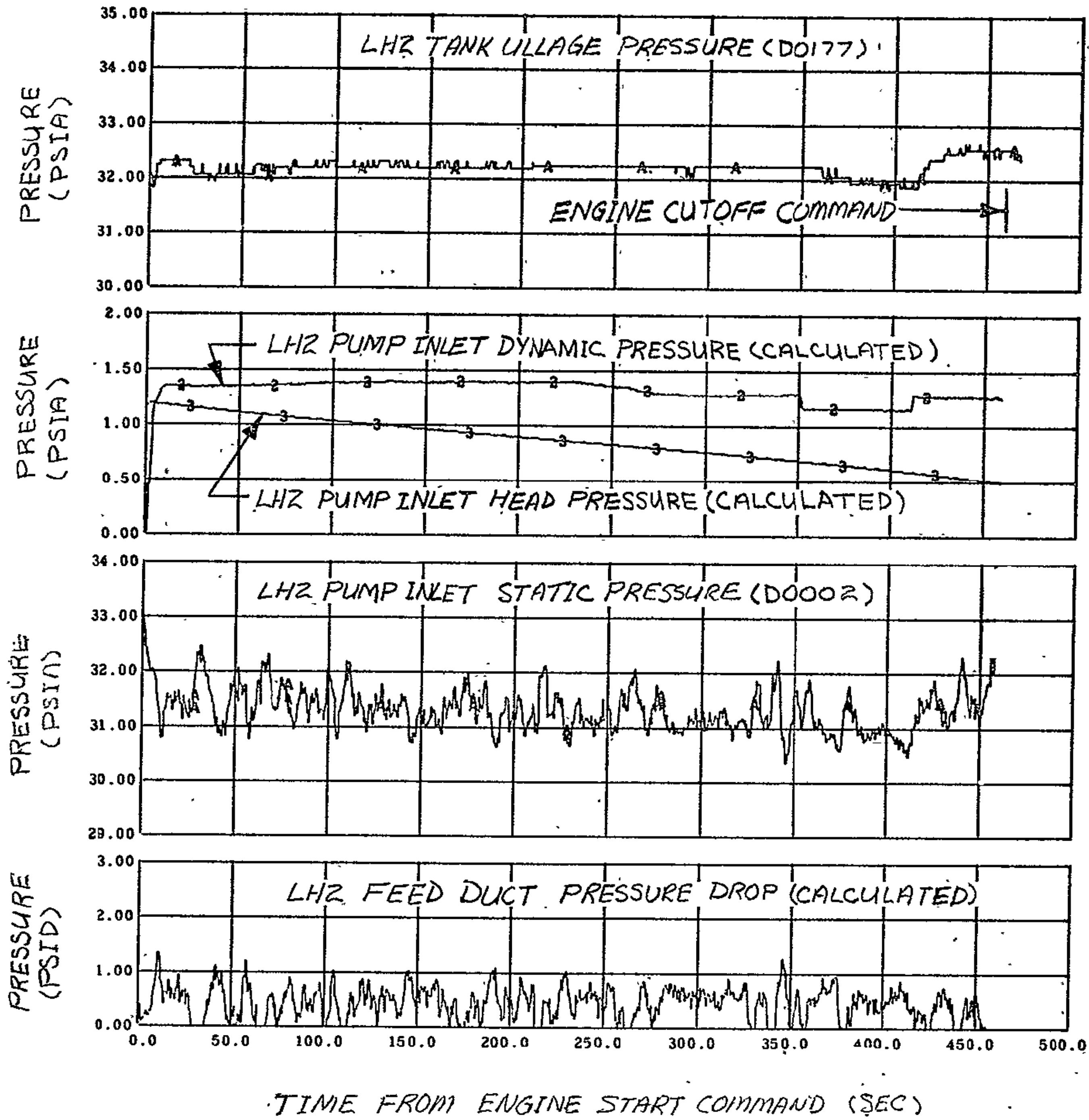


FIGURE 8-8. LH2 PUMP INLET CONDITIONS (SHEET 2 OF 2)

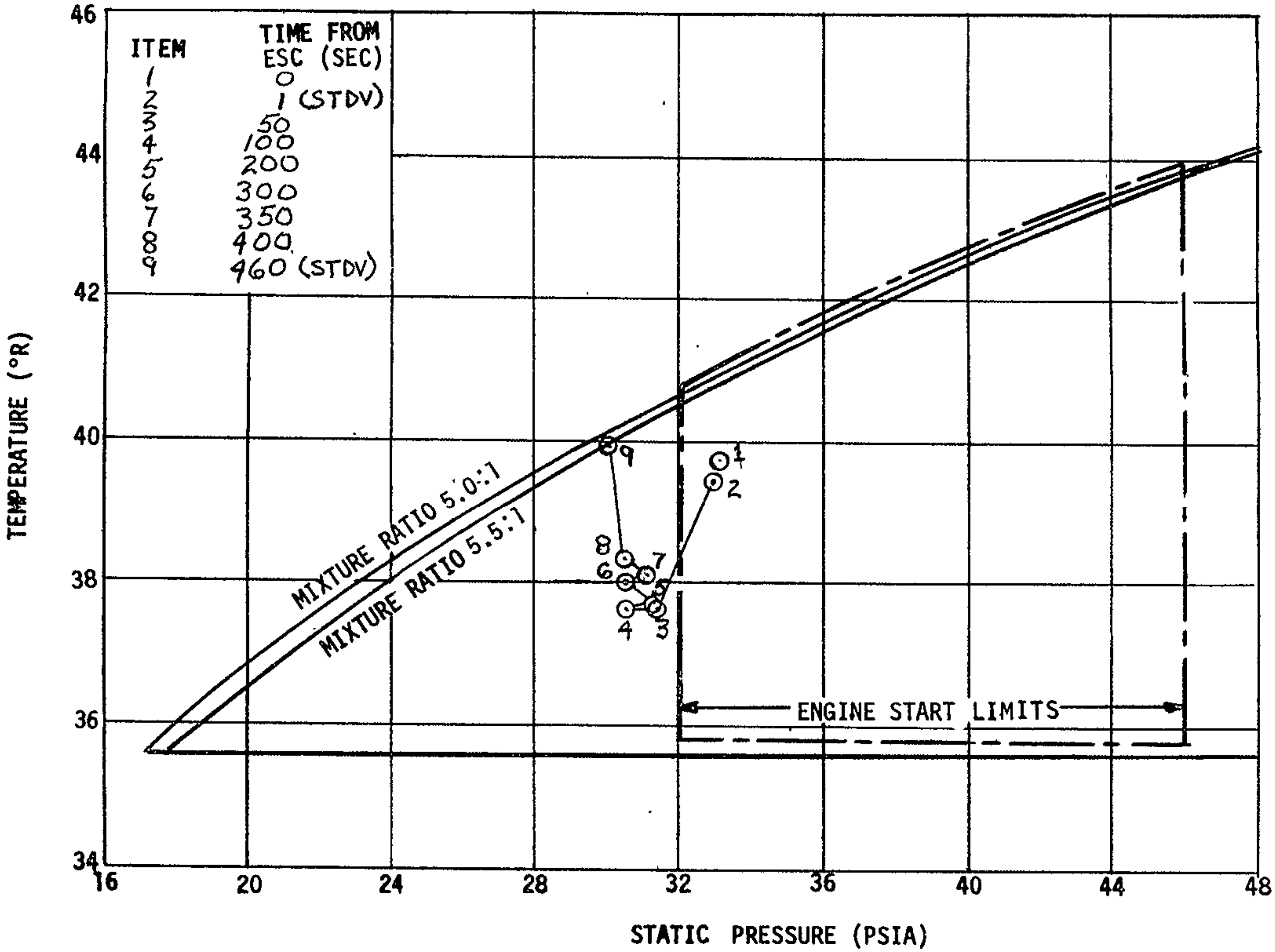


Figure 8-9. LH2 Pump Inlet Conditions During Firing

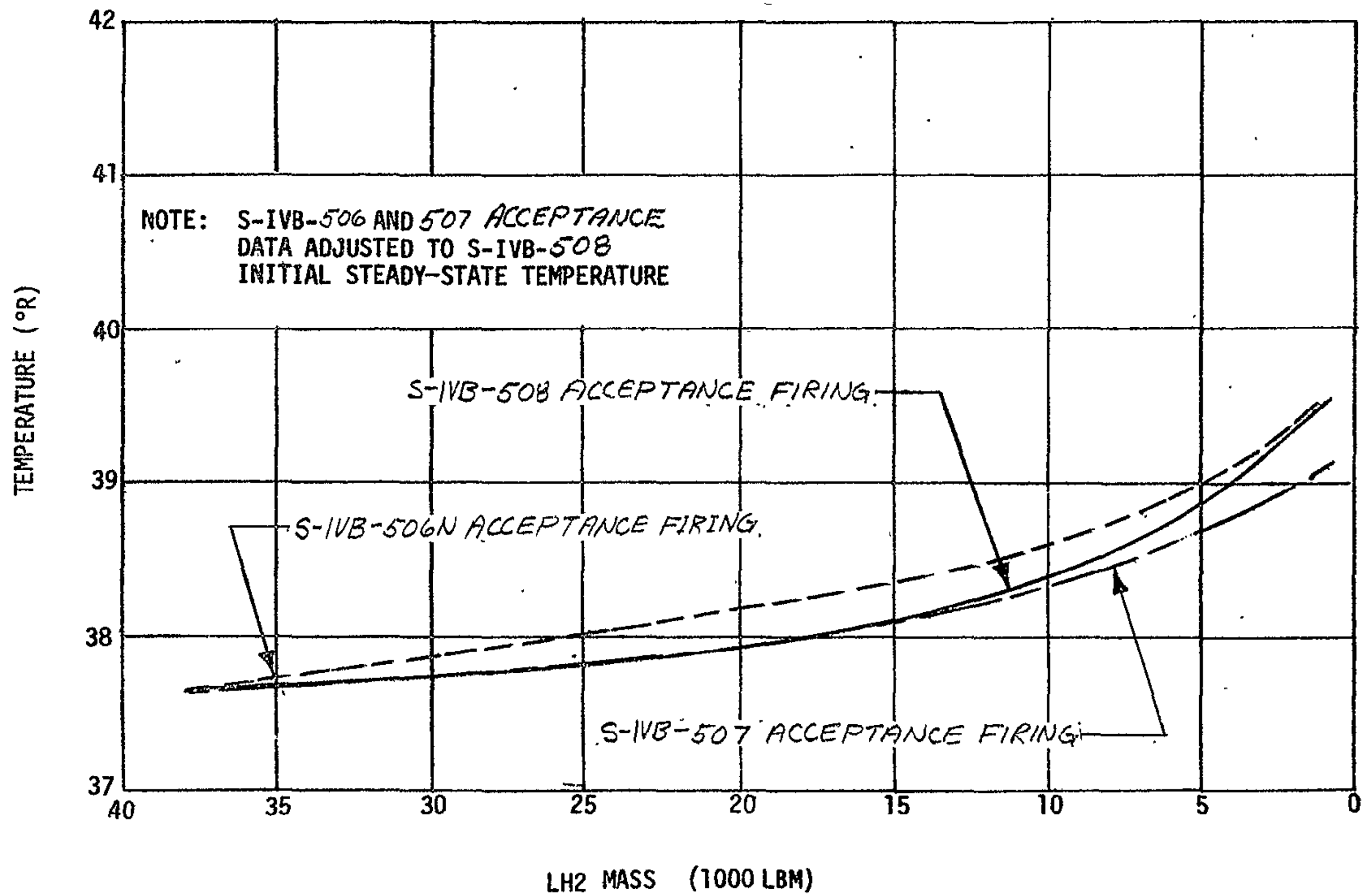


Figure 8-10. Effect of LH2 Mass Level on LH2 Pump Inlet Temperature

SECTION 9

PNEUMATIC CONTROL AND PURGE SYSTEM

9. PNEUMATIC CONTROL AND PURGE SYSTEM

The pneumatic control and purge system (figure 3-1) performed adequately during the acceptance firing. All components functioned properly. The test results are summarized and compared with previous acceptance firing data in table 9-1.

9.1 Ambient Helium Supply

In order to simulate actual flight conditions the stage was isolated from the ground support equipment (GSE). The helium supply valve was closed 328.5 seconds prior to simulated coast and remained closed during the continuous venting period and both the burner and ambient helium repressurization operations. The valve was also closed at SLO -7.2 seconds and remained closed through J-2 engine operation.

9.2 Pneumatic Control

All engine and stage pneumatic control valves responded properly throughout the terminal countdown, simulated coast, O2-H2 burner operation, ambient repressurization, and J-2 engine operation.

During a period of simulated coast the pressure decay of the control helium sphere was higher than normal. This was due to the high bleed rate that accompanies actuation of the latch in the LH2 latching vent and relief valve. The latch in the LH2 latching vent and relief valve remained actuated from *BSC -1,192 seconds to BSC +784 seconds.

The normal system pressure drops that result from regulator operation during J-2 engine and O2-H2 burner operation are shown in figures 9-1 and 9-2, respectively.

9.3 Ambient Helium Purges

During the acceptance firing all stage purge functions that utilize stage pneumatics were satisfactorily accomplished. The pneumatic system was isolated from the GSE during the periods of simulated coast and engine firing, discontinuing those purges that were facility supplied. Table 3-2 lists the flowrates of the various purge orifices.

*Burner Start Command

TABLE 9-1

PNEUMATIC CONTROL AND PURGE SYSTEM DATA

Parameter	S-IVB-508		S-IVB-507		S-IVB-506N	
	Engine Operation	Burner Operation	Engine Operation	Burner Operation	Engine Operation	Burner Operation
Sphere volume (cu ft)	4.5	4.5	4.5	4.5	4.5	4.5
Sphere pressure						
At simulated liftoff (psia)	2,950	--	2,966	--	2,817	--
At engine start command (psia)	2,875	2,540	2,855	2,175 1,941*	2,709	2,159 1,965*
At engine cutoff command (psia)	2,860	2,500	2,852	2,024 1,903*	2,713	2,099 1,950*
Sphere temperature						
At simulated liftoff (deg R)	547	--	540	--	549	--
At engine start command (deg R)	540	532	534	526 523*	541	537 536*
At engine cutoff command (deg R)	540	531	533	523 522*	541	537 536*
Helium mass usage rate						
Pre-burn engine pump purge (lbm/min)	0.075	--	0.070	--	0.080	--
Post-burn engine pump purge (lbm/min)	0.120	--	0.146	--	0.125	--
Simulated coast with no engine pump purge (lbm/min)	0.027	--	0.010	--	0.0033	--

*Value obtained from second burner operation.

Table 9-1 (Continued)

Parameter	S-IVB-508		S-IVB-507		S-IVB-506N	
	Engine Operation	Burner Operation	Engine Operation	Burner Operation	Engine Operation	Burner Operation
Burn duration (sec)	460	460	436	455 130*	448.1	456 130*
Helium mass						
At simulated liftoff (lbm)	8.12	--	8.39	--	7.89	--
At engine start command (lbm)	8.01	7.27	8.19	6.46 5.85*	7.71	6.29 5.78*
At engine cutoff command (lbm)	8.01	7.16	8.19	6.07 5.74*	7.71	6.13 5.74*
Usage during engine or burner operation (lbm)	0.0	0.11	0.0	0.39 0.11*	0.0	0.16 0.04*
Usage during 10-min post-burn engine pump purge** (lbm)	1.20	--	1.46	--	1.25	--
Maintained regulator outlet pressure band						
Low (psia)	550	548	534	540 540*	513	510 510*
High (psia)	565	552	565	543 542*	556	543 540*
System minimum during start and cutoff transient (psia)	440	--	426	--	423	--
Average LOX chilldown motor container purge pressure (psia)	45	46	61	60	57	57 56*

* Value obtained from second burner operation.

** Estimated on basis of purge flowrate.

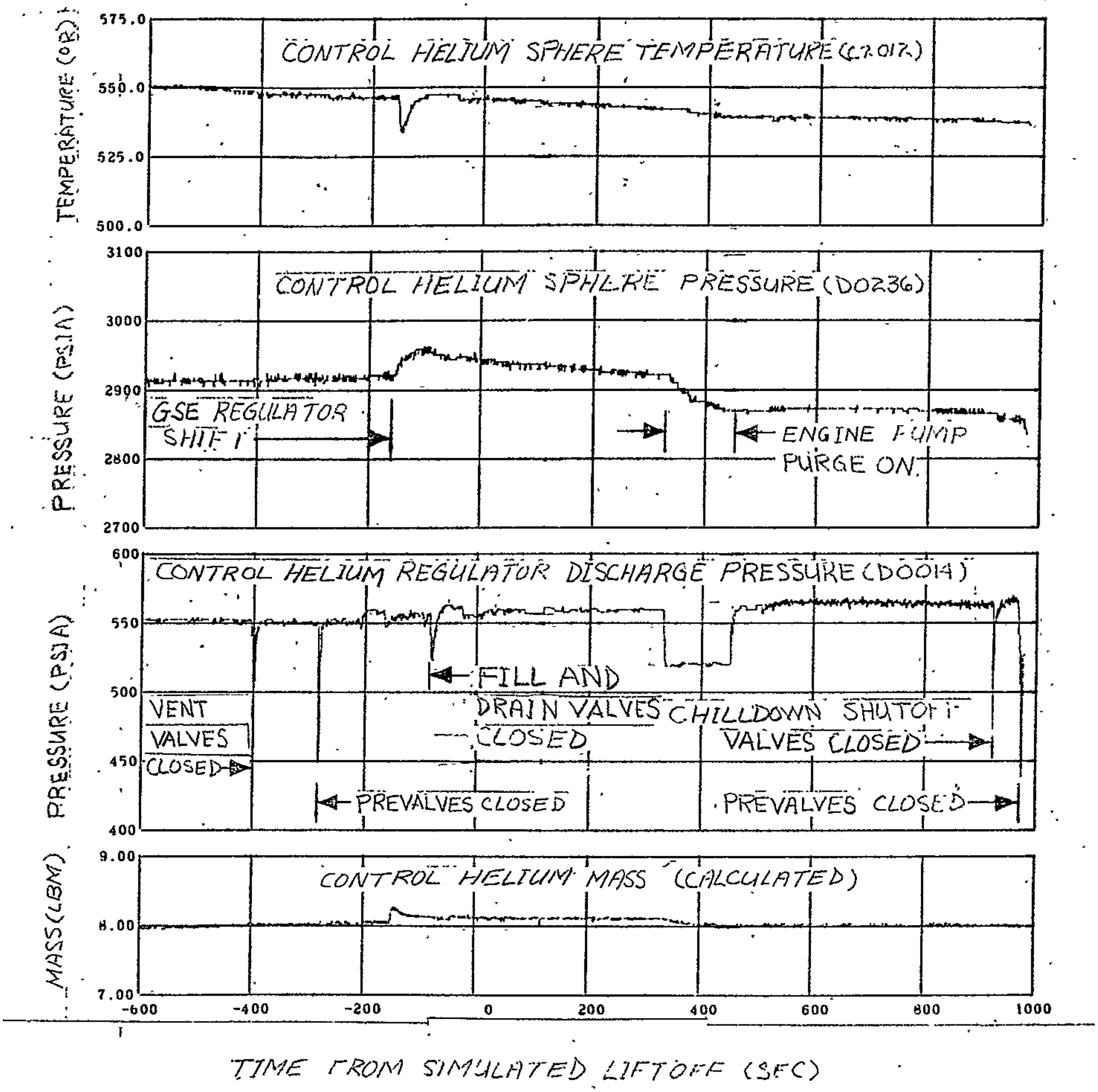


FIGURE 9-1. PNEUMATIC CONTROL AND PURGE SYSTEM PERFORMANCE

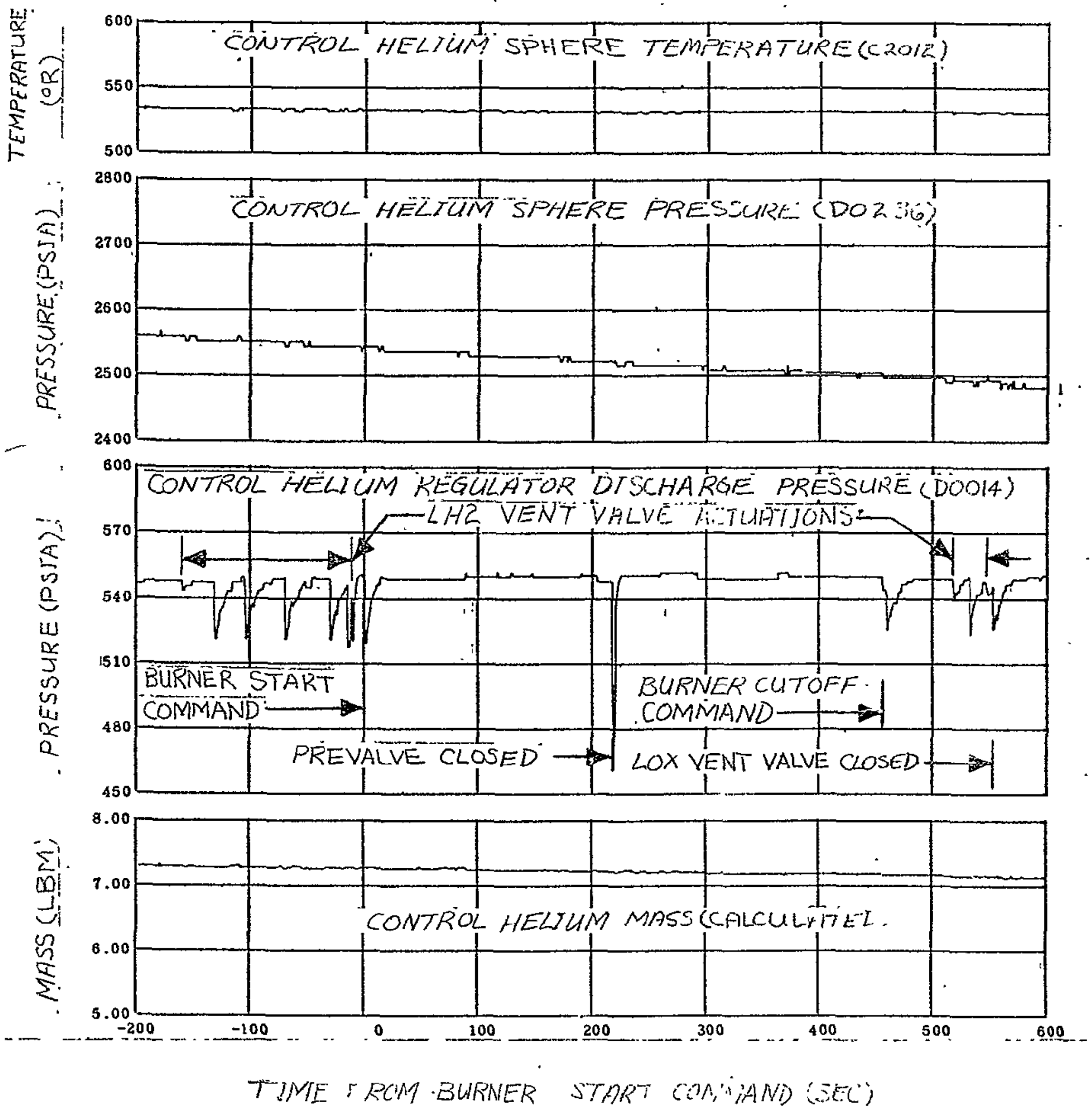


FIGURE 9-2. PNEUMATIC CONTROL SYSTEM CONDITIONS DURING O_2-H_2 BURNER OPERATION

SECTION 10

OXYGEN-HYDROGEN BURNER SYSTEM

10. OXYGEN-HYDROGEN BURNER SYSTEM

The O2-H2 burner (figure 3-1) was acceptance tested prior to the S-IVB-508 stage acceptance firing. The 508 test differed from previous acceptance tests in two ways. The S-IVB-503N, 504N, and 505N burner operations were terminated by pickup of the LH2 flight control pressure switch, whereas the 506N, 507, and 508 burner operations were not. In addition, the burner was operated twice during the 506N and 507 acceptance tests--the first time to repressurize the LH2 and LOX tanks, and the second to show the burner restart capability for ullaging purposes. On S-IVB-508, however, the burner was operated only once.

10.1 Burner Performance

The burner performed satisfactorily during the 460 seconds of operation. The LOX tank was repressurized 178 seconds after burner start, and the LH2 tank repressurization was terminated approximately 3.9 seconds later. Performance data are presented in figures 10-1 through 10-4.

10.2 LH2 Tank Repressurization

The LH2 tank pressurant started flowing 7.49 seconds after burner start command. The LH2 tank ullage was then pressurized from 19.3 to 30.3 psia in 174.5 seconds, for an average rate of 3.78 psi/min.

The 3.78 psi/min repressurization rate was 0.62 psi/min higher than the theoretical rate based on an adiabatic repressurization process, utilizing 40 deg R helium. The higher than theoretical pressurization rate was the result of the relatively warm temperatures of the cold helium spheres. The ambient heating on the S-IVB-508 burner was less than on the 506N and 507 burners due to the different cold helium sphere conditions on the various tests.

The LH2 tank repressurization burner heat input rate (the total minus the ambient heating rate), helium flowrate, and repressurization coil outlet temperature are shown in figure 10-2 and further discussed in paragraph 8.1.3. A comparison of O2-H2 burner performance during three acceptance firings is presented in table 10-1.

10.3 LOX Tank Repressurization

The LOX tank pressurant started flowing 7 seconds after burner start command. The LOX tank ullage was then repressurized from 34.5 to 37.9 psia in 171 seconds, for an average rate of 1.19 psi/min. To compensate for the 4.64 psia head due to the LOX load during ground testing, the ullage pressure was kept low enough to provide a burner LOX supply pressure range of 39.1 to 42.5 psia.

The total average LOX tank repressurization heat flux (the heating of the LOX tank pressurant gas from the 40 deg R reference base to the burner LOX repressurization outlet temperature) was 47,100 Btu/hr. Ambient heating (the heating of the LOX tank pressurant gas from the 40 deg R reference base to the burner inlet temperature) contributed approximately 10,200 Btu/hr to the total LOX tank repressurization heat flux. As a result of the cold helium sphere temperatures, the ambient heating and the LOX repressurization heat flux were comparable to those on previous acceptance tests. Approximately 3.6 lbm of helium were required for LOX tank repressurization.

The LOX tank repressurization burner heat input rate (the total minus the ambient heating rate), helium flowrate, and repressurization coil outlet temperature are shown in figure 10-4 and are further discussed in paragraph 7.1.3. The 508 acceptance firing LOX tank repressurization performance is compared with 507 and 506N acceptance performance in table 10-1.

10.4 Cold Helium Supply

The cold helium spheres provided an adequate amount of helium for cryogenic repressurization. The temperature and pressure profiles before and during burner operation were as expected and are shown in figure 10-4. The system performance is compared with previous acceptance tests in table 10-1.

10.5 Pilot Bleed Flowrate

The burner helium shutoff valves utilize a pilot bleed system which diverts approximately 0.004 lbm/sec of the total cold helium flow passing through each module and dumps it downstream of the burner exit orifices. This pilot bleed flow is compared with that during the S-IVB-507 and 506N tests in table 10-1.

TABLE 10-1

O_2-H_2 BURNER PERFORMANCE DATA

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
Duration of burner operation			
First burn	459.6	455.5	456
Second burn	N/A	130.6	130.6
Lag in pressurant flow after burn start (sec)	7.49	6.87	6.84
Cold helium supply			
Initial pressure (psia)	1,625	1,763	1,819
Initial average temperature (deg R)	61.6	64.0	60.3*
Initial mass (lbm)	223	224	252
Consumption during burner operation (lbm)	25.0	22.5	22.9
Burner propellant supply during repressurization period			
LH2 supply pressure range (psia)	20.2-31.2	20.9-31.1	20.5-31.1
LOX supply pressure range (psia)	39.1-42.5	38.3-41.1	39.3-43.2
LH2 tank pressurization			
Ullage volume (cu ft)	4,697	4,619	4,880
Initial pressure (psia)	19.3	20.0	19.6
Final pressure (psia)	30.3	30.2	30.2
Average pressurization rate (psi/min)	3.78	4.05	4.30
Total average heat transfer rate** (Btu/hr)	244,000	243,000	234,000
Ambient heating rate** of pressurant gas (Btu/hr)	53,350	64,000	66,536
Pressurant helium through burner (lbm)	19.36	18.1	16.5
Pressurant helium through valve pilot bleed (lbm)	0.74	0.61	0.9
Total helium required (lbm)	20.10	18.71	17.4

* Weighted average

** Measured from 40 deg R reference base

Table 10-1 (Continued)

Parameter	S-IVB-508	S-IVB-507	S-IVB-506N
LOX tank pressurization			
Ullage volume (cu ft)	974	969	999
Initial pressure (psia)	34.5	33.7	34.7
Final pressure (psia)	37.9	36.5	38.6
Average pressurization rate (psi/min)	1.20	1.11	1.16
Total average heat input rate* from burner (Btu/hr)	47,093	48,200	48,880
Ambient heating rate* of pressurant gas (Btu/hr)	10,188	11,500	10,980
Pressurant helium through burner (lbm)	2.90	3.2	4.3
Pressurant helium through valve pilot bleed (lbm)	0.71	0.61	1.2
Total helium required (lbm)	3.61	3.81	5.5

* Measured from 40 deg R reference base

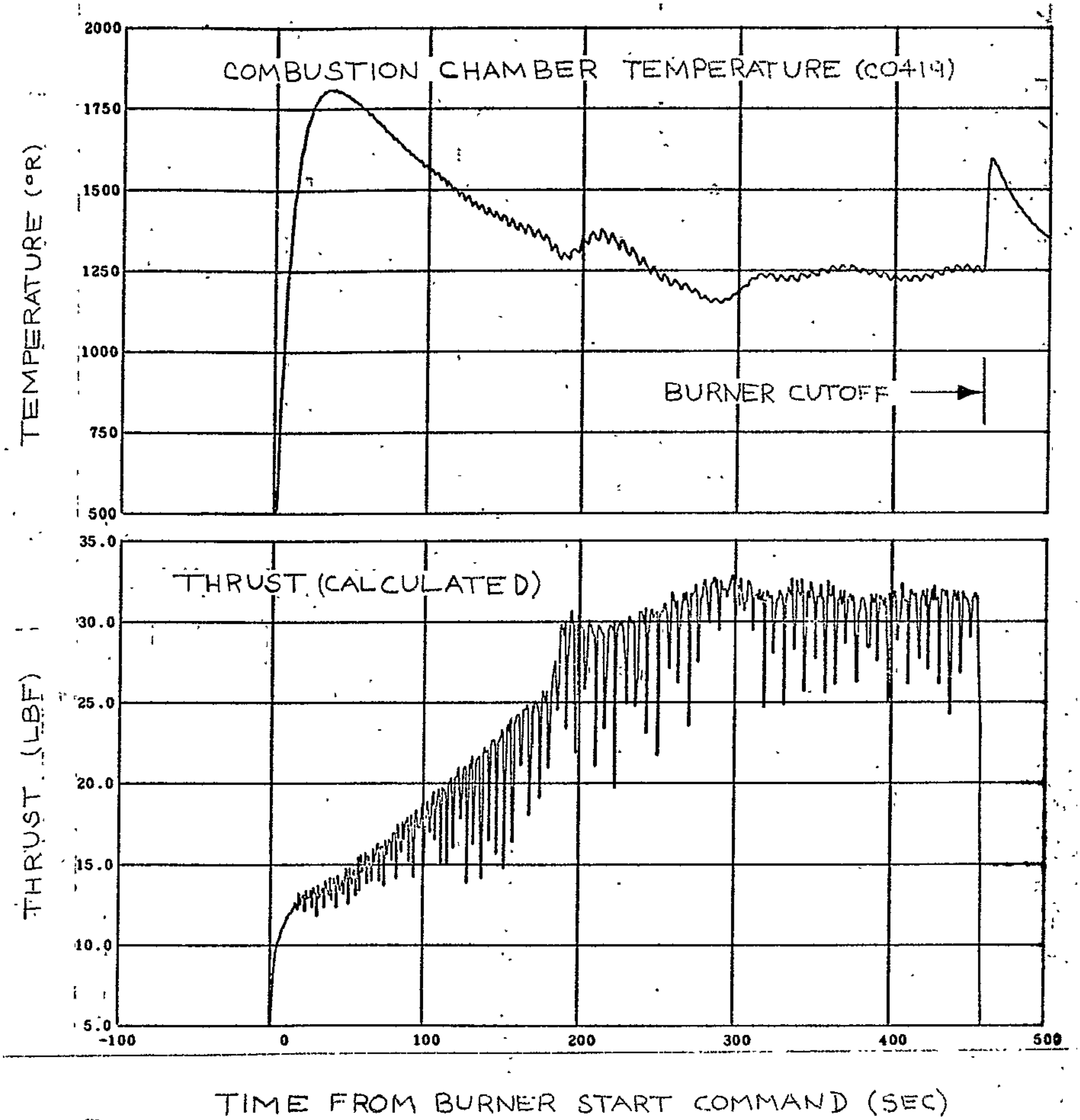


FIGURE 10-1. BURNER OPERATION (SHEET 1 OF 2)

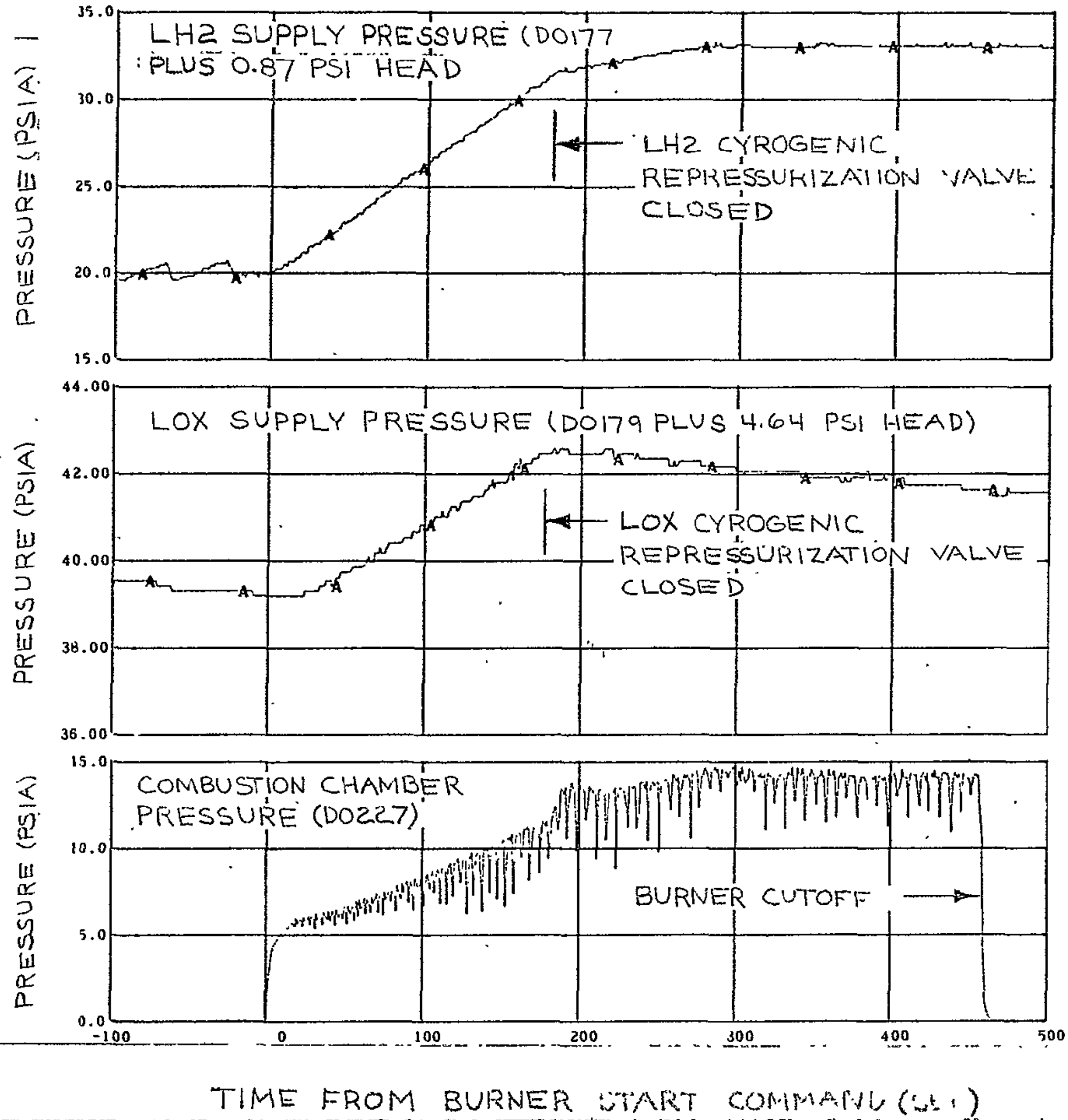


FIGURE 10-1. BURNER OPERATION (SHEET 2 OF 2)

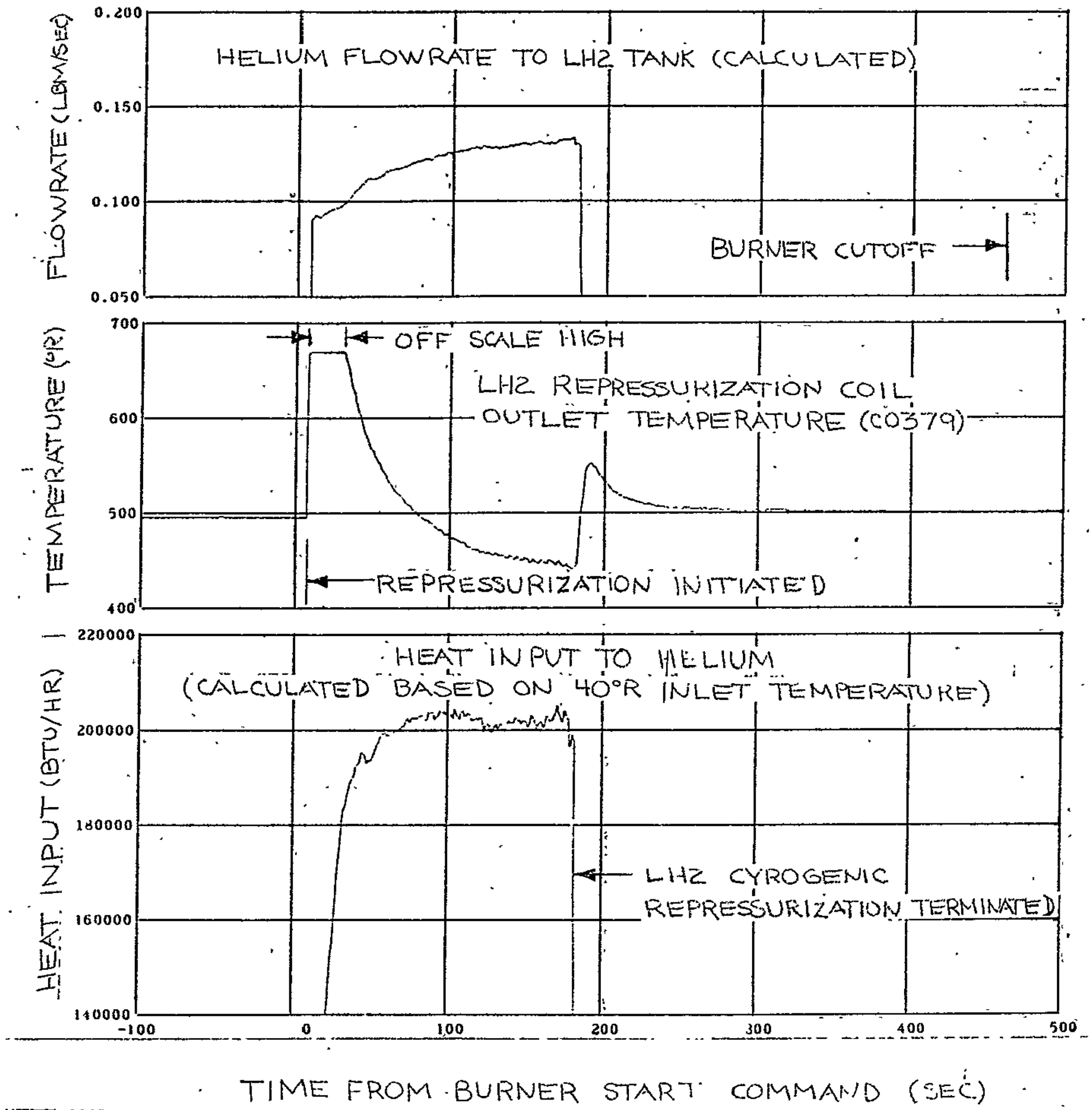


FIGURE 10-2. LH2 TANK REPRESSURIZATION

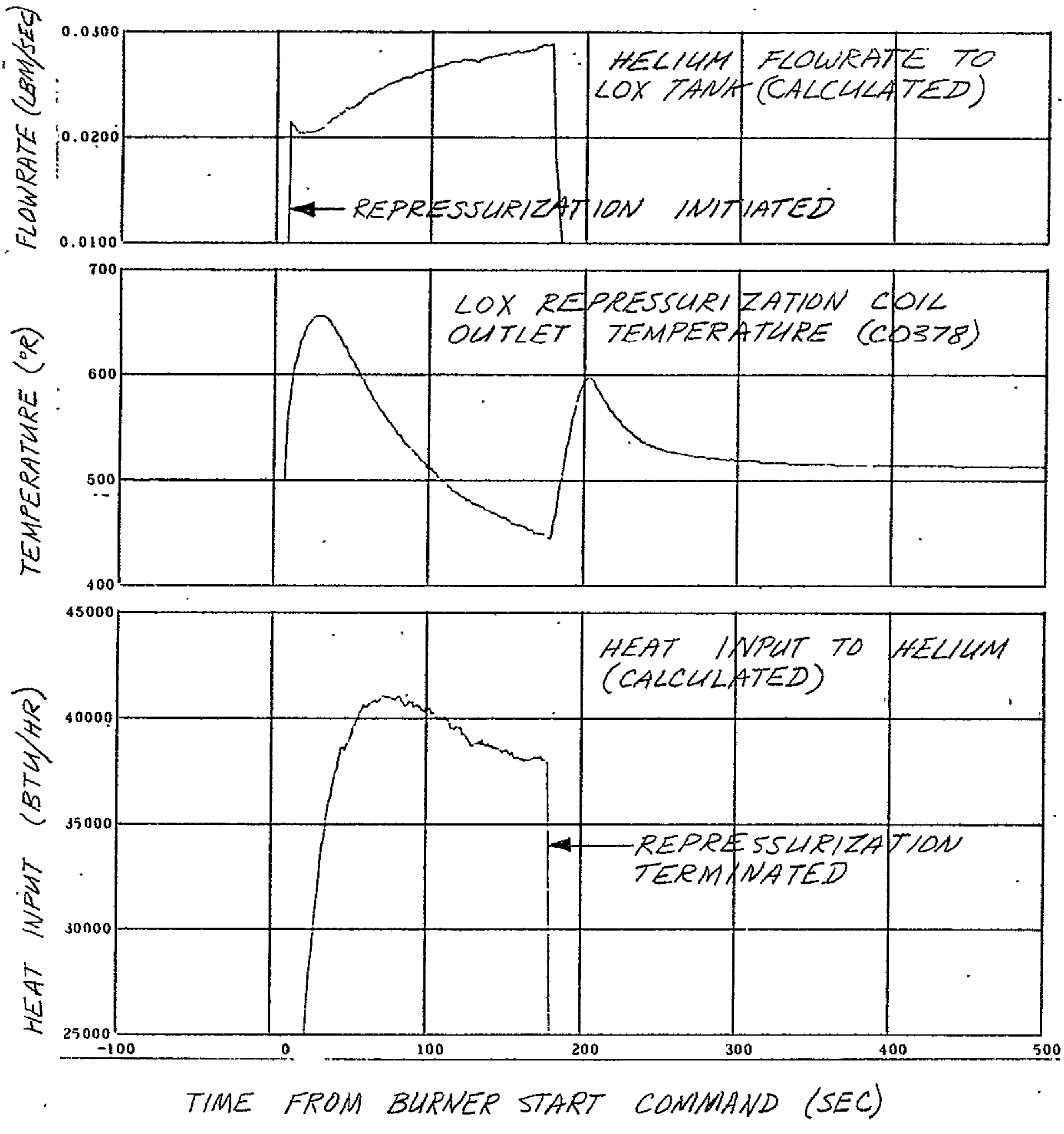


FIGURE 10-3. LOX TANK REPRESSURIZATION

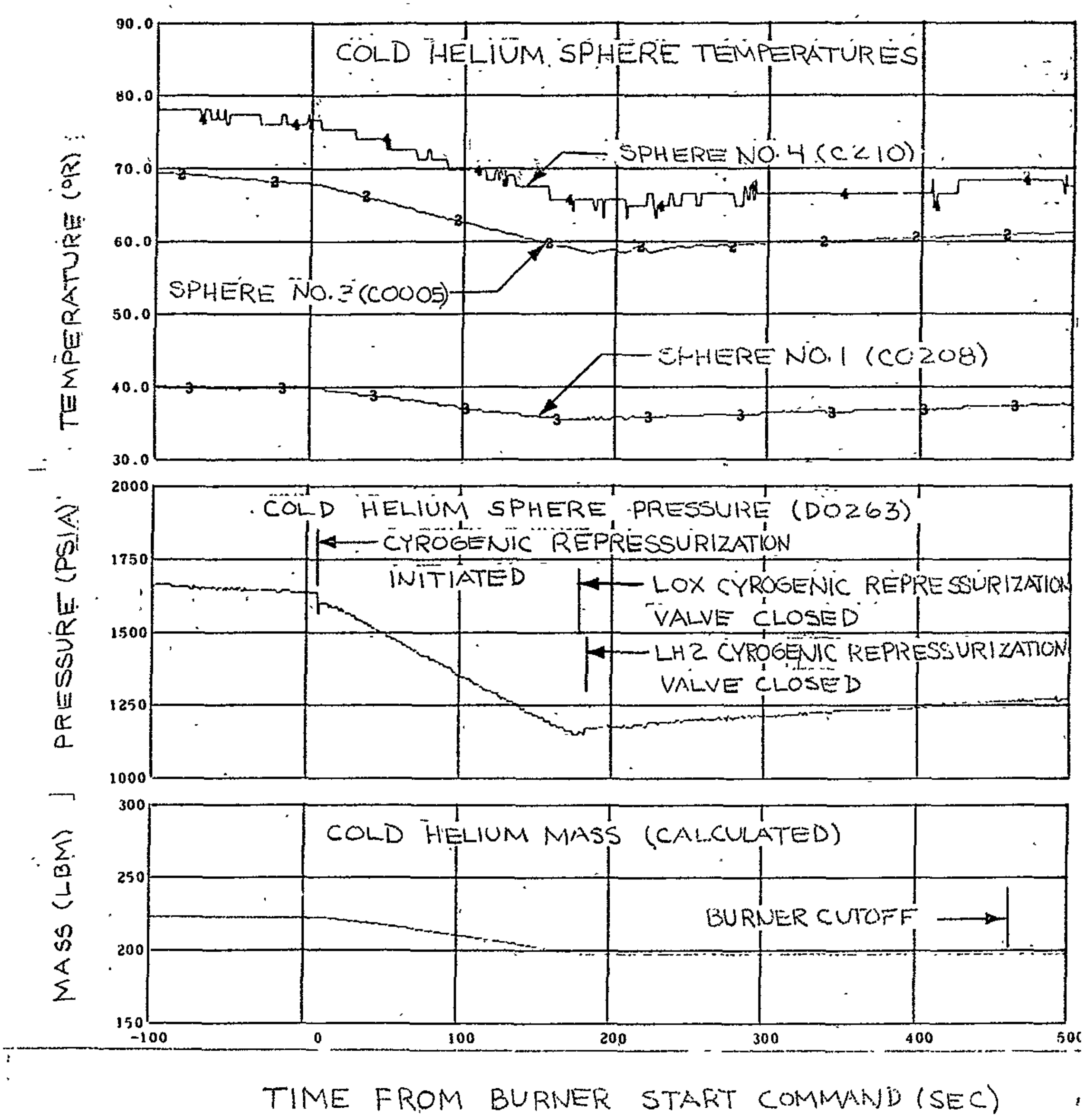


FIGURE 10-4. COLD HELIUM SPHERE CONDITIONS DURING O2-H2 BURNER OPERATION

SECTION 11

PROPELLANT UTILIZATION SYSTEM

11. PROPELLANT UTILIZATION SYSTEM

The propellant utilization (PU) system generally performed satisfactorily during the acceptance firing, however, a minor anomaly with a sticky PU valve compromised the valve history. Propellant loading was successfully accomplished based upon a desired common propellant load of 193,273 lbm LOX and 38,000 lbm LH2. The LOX and LH2 masses obtained by the flow integral method were 193,079 lbm and 37,711 lbm, respectively. The PU indicated LOX and LH2 masses were 0.06 percent and 0.85 percent higher than the flow integral derived masses.

The PU indicated LOX mass was 0.04 percent less than the desired LOX loading and the PU indicated LH2 mass was 0.08 percent greater than the desired LH2 load. The LOX and LH2 full load masses, as determined by the volumetric method, were respectively, 0.06 percent lower and 0.81 percent higher than the flow integral method derived mass. Loaded mass as determined by the flow integral method was -.10 percent and -.77 percent of desired for LOX and LH2, respectively.

The PU system operated in a closed-loop mode for most of the single burn full duration firing. However, an open-loop excursion to the low EMR position (4.5:1.0) was commanded at 350.4 sec followed by a command to the null position (5.0:1.0) at 410.1 sec where it remained until cutoff. During the closed-loop operation a reference mixture ratio of 5.0:1.0 was utilized. Closed-loop valve cutback occurred 10.7 sec later than predicted. The steady-state valve position following the closed-loop cutback transient was approximately $\overline{0.6}$ deg higher than predicted.

The open-loop excursion resulted in an LH2 depletion cutoff. The resulting propellant masses at cutoff were 3,300 lbm LOX and 670 lbm LH2.

Engine thrust variation were well within the flight thrust variation limits derived for the Contract End Item (CEI) specification.

11.1 PU System Calibration

The nominal S-IVB-508 pre-acceptance mass sensor calibration data were determined from previous acceptance firing results.

The propellant mass at the upper and lower calibration point was determined from calculated unique tank volume data and predicted propellant densities. The capacitance at the lower end was determined from

the vendor's sensor air capacitance and average fast drain data from previous acceptance firings.

The LOX sensor capacitance at the full immersion point was determined from the vendor's air capacitance and mean data accumulated from LOX sensor full immersion tests conducted on S-IVB-207, 208, 209, 503N, and 504N. The LH2 sensor capacitance at the upper calibration point was determined from the S-IVB-209, 504N, 505N, and 506 immersion test results and vendor's air capacitance.

The LOX and LH2 PU calibration data are presented in the following table:

PU MASS SENSOR	MASS (lbm)	CAPACITANCE (pf)	LOCATION
LOX	196,748	414.12	Top of inner element.
	1,335	282.06	Bottom of inner element.
LH2	44,694	1185.26	Top if inner element.
	201	971.36	Bottom of inner element.

11.2 PU Mass History

The flow integral, volumetric, and PU indicated methods were used to evaluate the acceptance firing propellant full load and mass history; however, only the flow integral method will be used to recalibrate the PU system for flight.

The flow integral method consists of determining the mass flowrate of LOX and LH2 and integrating as a function of time to obtain total consumed mass during firing. Flow integral mass values are based on the analysis of engine flowmeter data, thrust chamber pressure, engine influence equations, and engine tag values.

The initial full load mass, using the flow integral method, is determined by adding the propellant residuals at engine cutoff, the fuel pressurant added to the ullage, and propellants lost to boiloff to the total mass consumed.

The PU volumetric masses were derived from raw PU probe output data computed according to volumetric calibration slopes and volumetric nonlinearities. The calibration slopes (lbm/pf) were computed from capacitance propellant mass relationships at the upper and lower probe active element extremities. The propellant mass at these extremities was calculated from unique tank volume determined from tank measurements and propellant density.

The PU indicated method measures propellant mass from the raw PU probe output.

Table 11-1 presents the propellant mass history for salient times during the acceptance firing.

11.2.1 Propellant Loading

Propellant loading was accomplished automatically by the loading computer. Desired, indicated, volumetric, and flow integral full propellant loads at ESC are presented in table 11-1.

The deviation between the desired and flow integral masses were within 0.10 percent and 0.77 percent for LOX and LH2 respectively.

11.2.2 Propellant Residuals

Propellant residuals were computed at Engine Cutoff Command (ECC) using both the PU mass sensors and the residual point level sensors. Three level sensors in each tank (L0017, L0018, and L0019 in the LH2 tank, and L0014, L0015, and L0016 in the LOX tank) were activated during the firing and were used for residual analysis.

Level sensor residuals were computed using the engine consumption data (G105 program) to extrapolate from level sensor activation to engine cutoff. A statistical average residual was computed for the point level sensors for each propellant tank. The final residual masses at engine cutoff are the weighted average residuals of the point level sensor and PU mass sensor residual data.

Table 11-2 contains a tabulation of PU volumetric, level sensor, and weighted average data. The residuals as determined from the weighted average data were 3,300 lbm and 670 lbm for LOX and LH2, respectively.

11.2.3 PU Efficiency

PU efficiency is determined by expressing the usable residual propellants at depletion as a percentage of the total propellant load. The planned residuals were not optimized to include the effects of the open-loop demonstration. An LH2 depletion sensor cutoff occurred prior to PU processor cutoff due to a propellant depression phenomena. Total stage propellant consumption rates (determined by engine and stage flowrate evaluation) at the LH2 depletion sensor cutoff time were 390.9 lbm/sec for LOX and 79.3 lbm/sec for LH2.

The combined PU efficiency (open and closed-loop) was 99.42 percent. The planned residuals were 2,408 lbm of LOX and 760 lbm of LH2. The actual extrapolated residuals result with no remaining usable LH2 and 3,264 lbm usable LOX remaining.

Normal cutoff is by the PU processor. For future acceptance fired stages an adjustment will be made to the LH2 PU processor cutoff so as to initiate engine cutoff prior to the depletion sensor activation.

11.3 PU System Response

PU system closed-loop mixture ratio valve cutback occurred at 196.7 sec which was 10.7 sec later than the predicted cutback time of 186.0 sec. The closed-loop valve response exhibited anomalous activity during the cutback transient. This anomaly was detected at a valve position of +25.5 degrees and was determined to have resulted from a sticky valve. During the subsequent post firing checkout the valve did not meet the specification requirement and was replaced.

Receipt of the open-loop 4.5 EMR command was observed within 0.4 sec of predicted. The PU valve null position command was received at 410.1 sec which is 0.1 sec later than predicted.

The reconstruction of the actual PU valve history was made using the actual engine environment, tank-to-sensor mismatches derived from the flow integral mass histories, and other known system operating conditions. The tank-to-sensor mismatch of the LOX and LH2 mass sensors based on volumetric and flow integral data are presented in figures 11-2 through 11-5.

The following table summarizes the deviations between the actual and predicted PU valve position histories and their sources, based on the flow integral results.

DESCRIPTION	CUTBACK TIME DEVIATION (sec)	VALVE POSITION SHIFT (deg)
Loading	-6.5	0
Calibration	0	+0.25
Tank/Sensor Mismatch	+12	0
Tag Values	+6	+2.39
Engine Environment	-2	+0.02
Total	+9.5	+2.66

The summation of deviations listed in the table would increase the predicted cutback time by 9.5 sec and increase the mean value of mixture ratio valve position by 2.6 deg.

11.3.1 PU Cutback Deviations

11.3.1.1 Loading Computer Deviation

Loading computer deviations are the difference between the PU system indicated loads at ESC and the desired PU system indicated loads at ESC. The loading deviations were -73 lbm LOX (-.038 percent) and +32 lbm LH2 (+.084 percent). These deviations were within acceptable loading errors of $\pm$3.0 percent. The combined effect of these loading computer deviations decreased cutback time by 6.5 sec. The mean level of the valve position after cutback was not affected by these loading computer deviations.

11.3.1.2 Flow Integral Mass/Capacitance Calibration Deviation

Calibration deviations are the difference between PU indicated loads and flow integral loads during burn. Calibration deviations at ESC were -.013 percent LOX and -.869 percent LH2. Calibration deviations at ECC were -.0226 percent LOX and +.0 percent LH2. The slope deviations between ESC and ECC were +.0094 percent LOX and -.869 percent LH2. The desired

reference mixture ratio (RMR) for the S-IVB-508 acceptance firing was 5.0:1.0. The bridge gain ratio (BGR) was also calibrated at 5.0:1. Since PU sensor calibration deviations also affect the BGR, the actual ratio was 5.02:1. The calibration deviations did not alter the cutback time but shifted the mean value of valve position by +.25 deg.

11.3.1.3 Tank/Sensor Mismatch

The effect of the differences between the average of previous acceptance firing flow integral tank-to-sensor mismatch results for the S-IVB-508 prediction and the actual flow integral mismatch increased cutback by 12 sec but had no effect on the mean level of valve position. Figures 11-4 and 11-5 show the actual flow integral LOX and LH2 nonlinearities with the snesor manufacturing nonlinearities included.

11.3.1.4 Tag Values

The effect of the difference between predicted and actual tag values for the S-IVB-508 acceptance firing was to increase cutback by 6 sec. In addition, the mean level of valve position was shifted by +2.39 deg.

11.3.1.5 Engine Environments

The effect of the difference between predicted and actual pump inlet conditions, pressurization, and boiloff rates for the 508 acceptance firing was to decrease cutback time by 2 sec and increase the mean level of valve position by +.02 deg.

TABLE 11-1
PROPELLANT MASS HISTORY

EVENT		DESIRED MASS (lbm)	PU INDICATED MASS (lbm)	PU VOLUMETRIC MASS (lbm)	FLOW INTEGRAL MASS (lbm)	DEVIATION FROM FLOW INTEGRAL MASS					
						DESIRED		PU INDICATED		VOLUMETRIC	
SIMULATED LIFTOFF (TO) AND ENGINE START COMMAND	LOX	193,273	193,200	192,967	193,079	+194	0.10%	+121	0.06%	-112	0.06%
	LH2	38,000	38,032	38,017	37,711	+289	0.77%	+321	0.85%	+306	0.81%
	TOTAL	231,273	231,232	230,984	230,790	+483	0.20%	+442	0.19%	+194	0.08%
PU VALVE CUTBACK (ESC +196.7 SEC)	LOX	105,325	106,658	106,058	105,715	-390	0.20%	+943	0.49%	+343	0.18%
	LH2	21,912	21,925	21,860	21,655	+257	0.68%	+270	0.71%	+205	0.54%
	TOTAL	127,237	128,583	127,918	127,370	-133	0.05%	+1,213	0.52%	+548	0.23%
ENGINE CUTOFF COMMAND	LOX	3,448	3,338	3,388	3,300	+148	0.08%	+38	0.02%	+88	0.05%
	LH2	985	643	651	670	+315	0.83%	-27	0.07%	-19	0.05%
	TOTAL	4,433	3,981	4,039	3,970	+463	0.20%	+11	0.004%	+69	0.03%

TABLE 11-2
PROPELLANT RESIDUAL SUMMARY

		LEVEL SENSOR (ACTIVATION TIME)						
		LOX TANK			LH2 TANK			
	L0016 (To +937.110)	L0015 (To +952.942)	L0014 (To +969.026)	ECC (To +971.681)	L0019 (To +937.443)	L0018 (To +945.610)	L0017 (To +963.026)	ECC (To +971.681)
PU VOLUMETRIC	16,941	10,337	4,276	3,388	3,456	2,789	1,460	651
LEVEL SENSOR INDICATED VALUE	16,683	10,659	4,325		3,381	2,733	1,362	
LEVEL SENSOR EXTRAPOLATED RESIDUAL	3,163	3,334	3,288	3,281 *	665	665	676	671 *
WEIGHTED AVERAGE RESIDUAL				3,300 **				670 **

NOTE: To = 1,433:44.00
*Statistical average of level sensor residuals
**Statistical average of level sensor and PU system residuals

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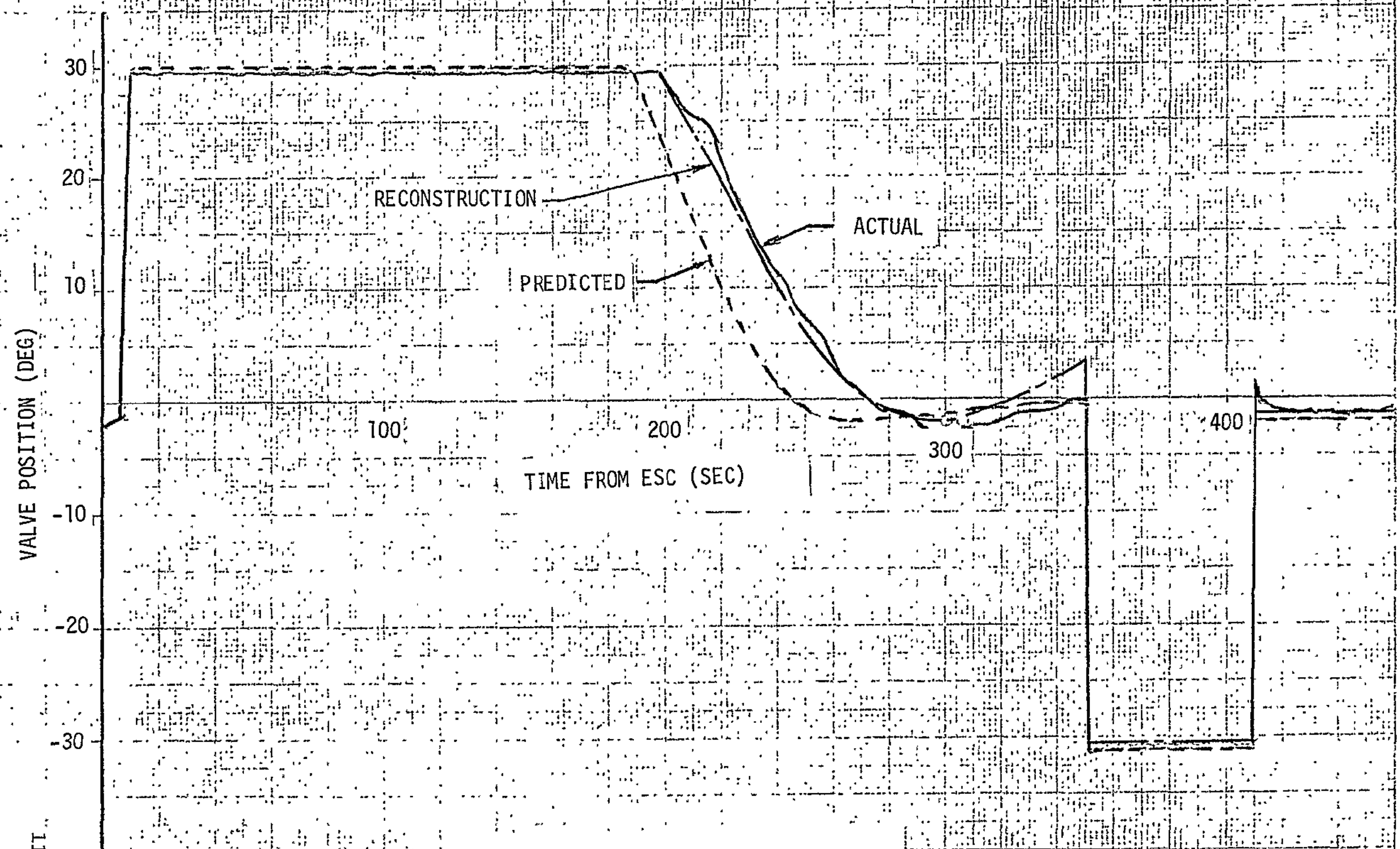

Figure 11-1. PU Valve Response

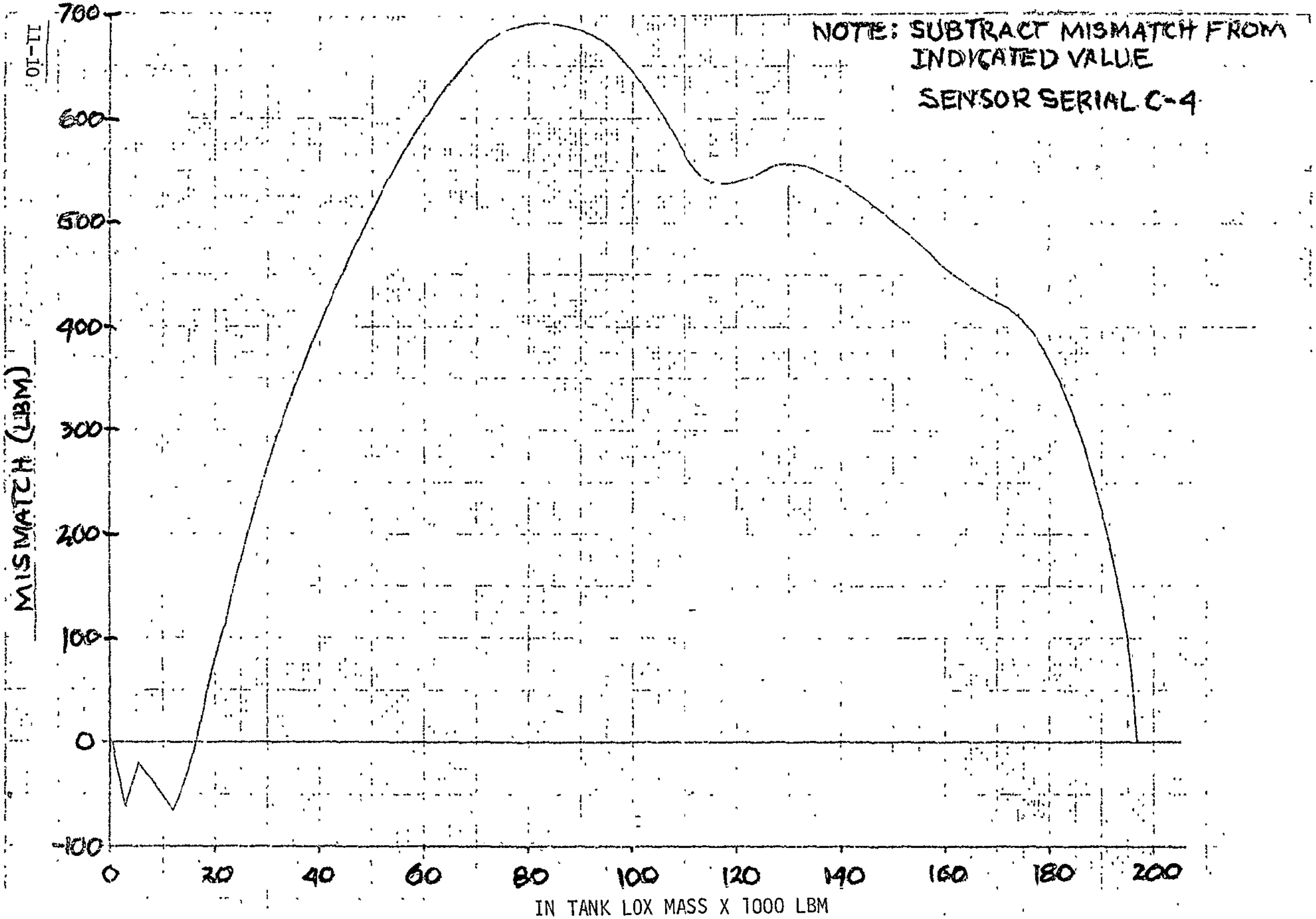

Figure 11-2. LOX Tank to Sensor Mismatch, Volumetric Method

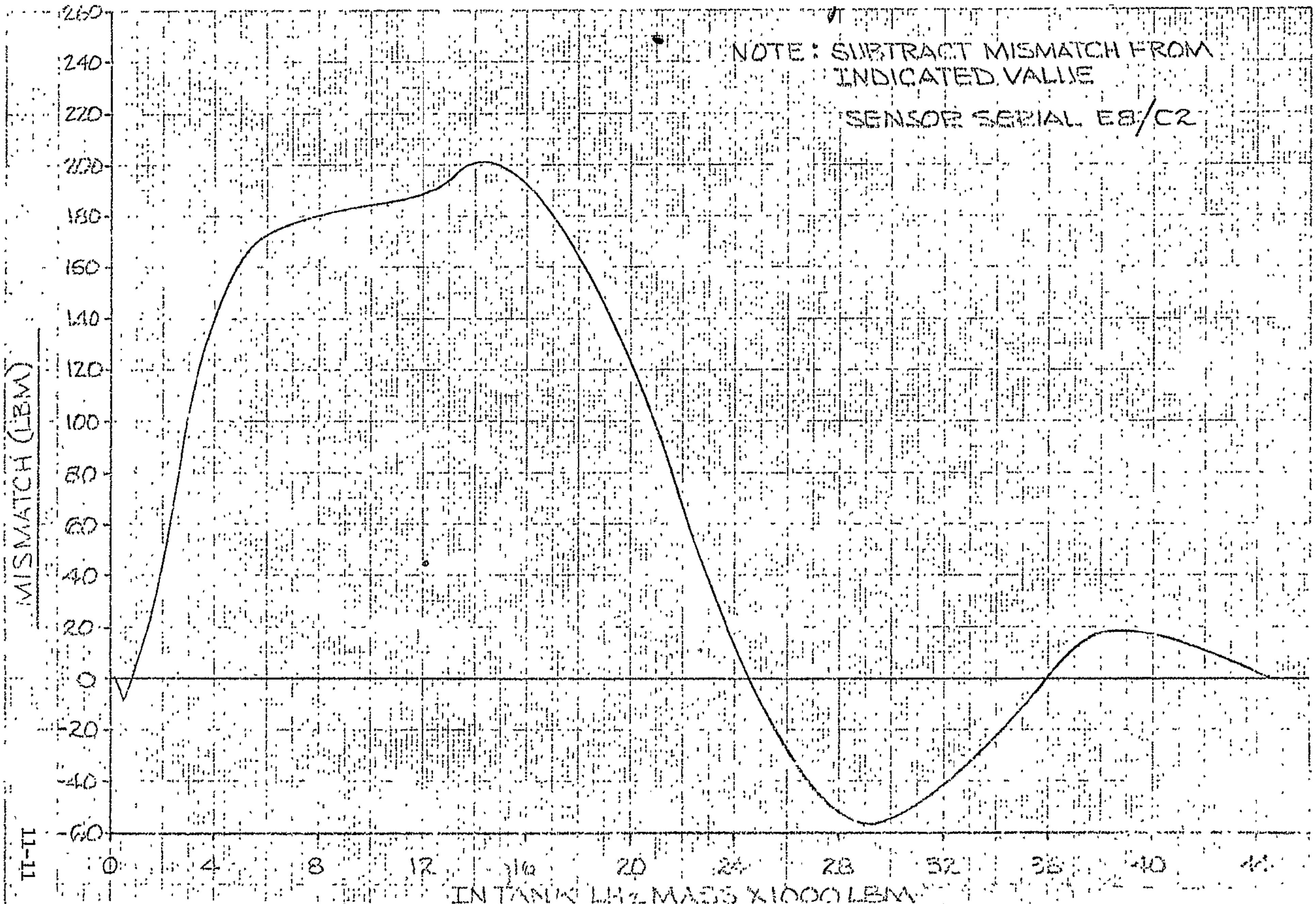

Figure 11-3. LH2 Tank to Sensor Mismatch, Volumetric Method

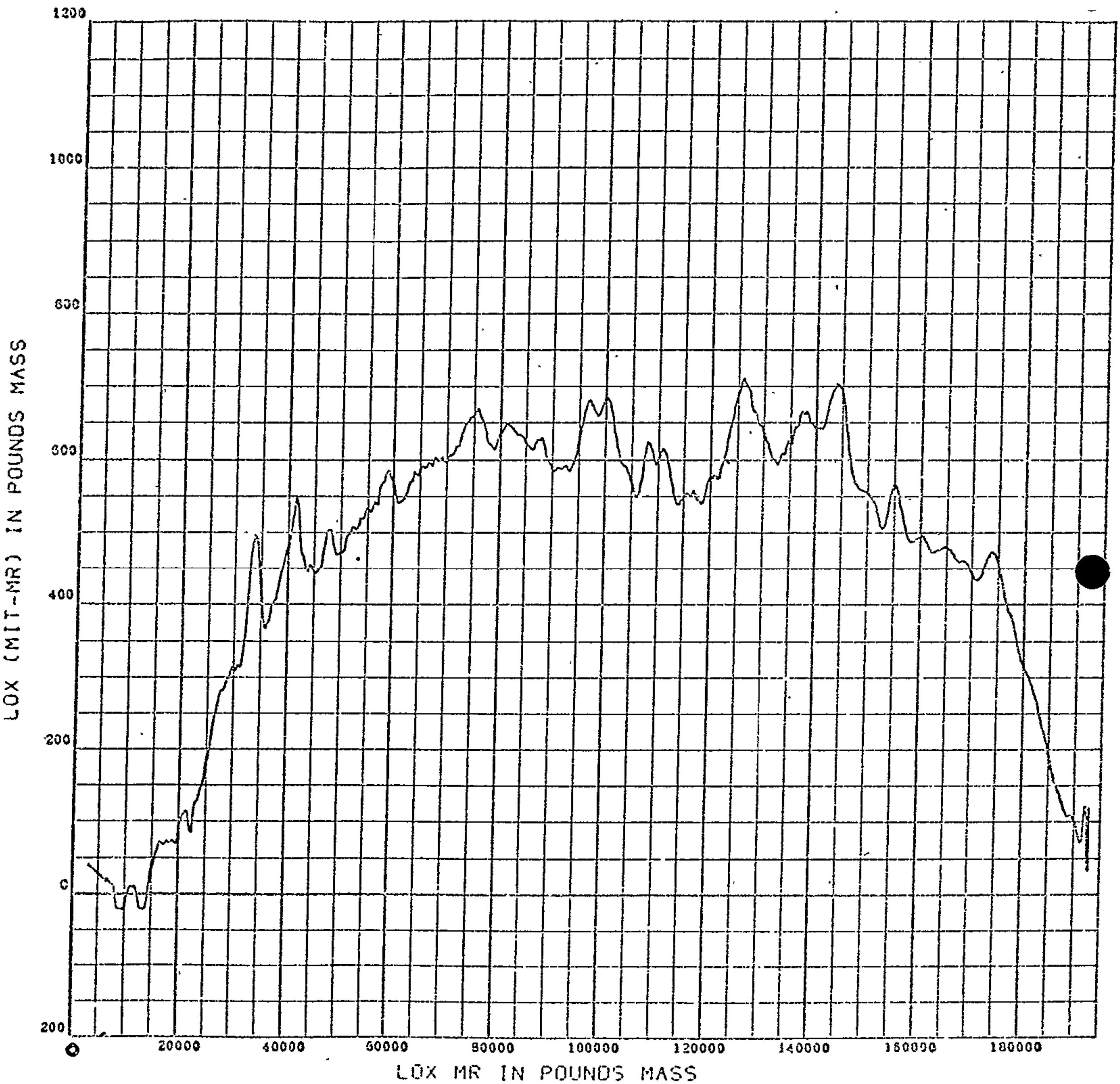

Figure 11-4. LOX Mass Sensor Nonlinearity (Flow Integral Method)

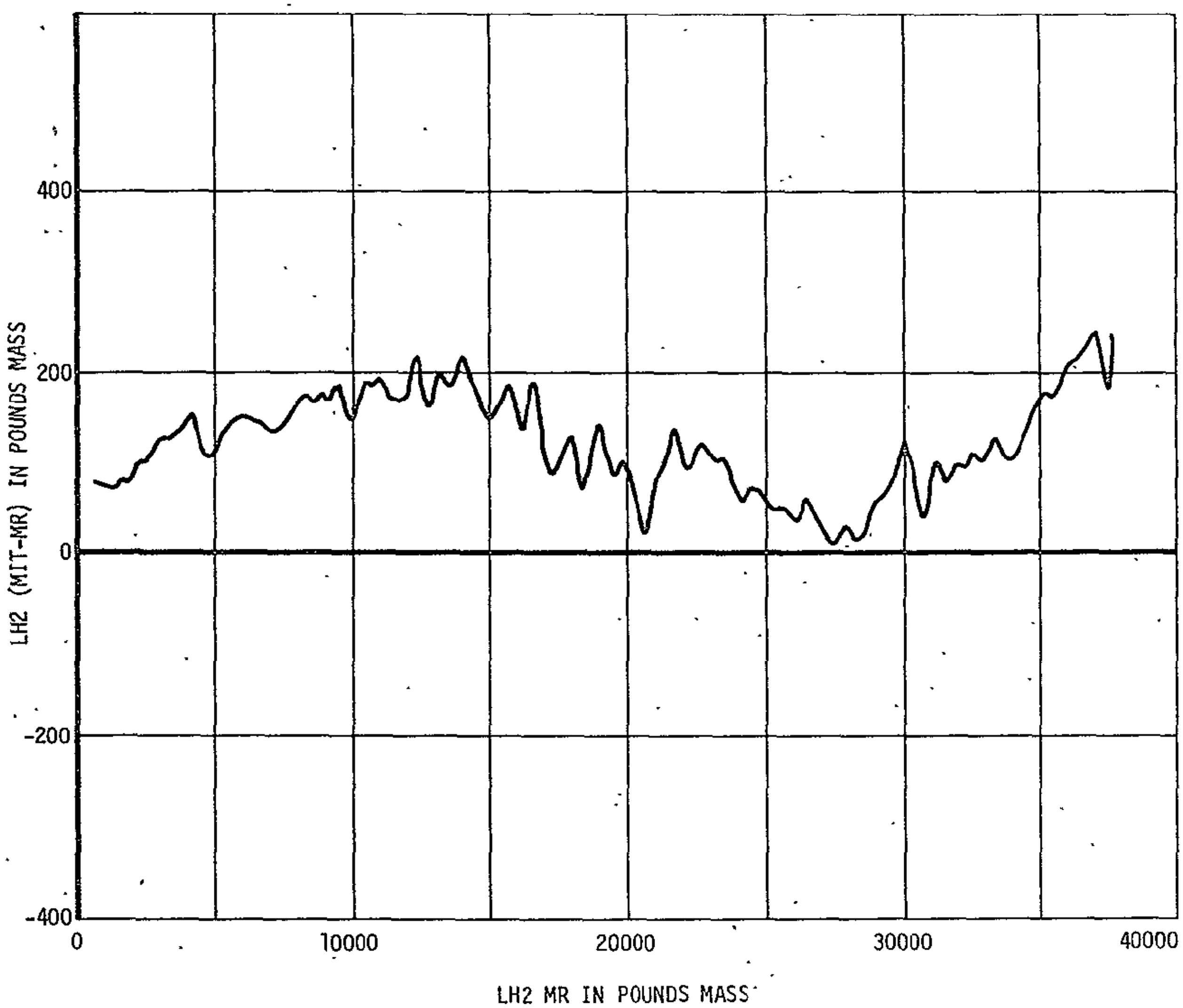

Figure 11-5. LH2 Mass Sensor Nonlinearity (Flow Integral Method)

SECTION 12

DATA ACQUISITION SYSTEM

12. DATA ACQUISITION SYSTEM

The data acquisition system demonstrated competency in acquiring stage information, conditioning the data signals, translating these signals into proper telemetry format, and transmitting the telemetry information to a ground station. The measurements which comprise this system are specified in Drawing No. 1B43573 Change S AEO U, Instrumentation Program and Components List (IP&CL); however, not all measurements specified in the IP&CL were in operation during this test. The system demonstrated that it was free of radio frequency interference and was electromagnetically compatible with other stage systems.

The performance of the data acquisition system was satisfactory throughout the O_2-H_2 burner and mainstage firing phases of the acceptance firing. The reduced data from all channels were acceptable with the exception of the discrepancies described in tables 12-1 and 12-2.

The following is a summary of the telemetry data measurement system performance during acceptance firing:

Total number of measurements assigned	296	
Total number of measurements deleted	67	
Total number of active measurements	229	
Measurement failures	3	
Total acceptable measurements	226	
Measurement efficiency	98.7	percent
Measurement discrepancies	9	

12.1 Instrumentation Subsystem Performance

The instrumentation system performed satisfactorily during all phases of the acceptance firing. Three measurement failures were observed and nine measurements exhibited data problems. Table 12-1 lists these measurements and table 12-2 elaborates their malfunction characteristics. Table 12-3 lists the measurements that were inactive.

Measurement G0010-401, Position - P.U. System Ratio Valve, was qualified as good, but the valve exhibited erratic operation. The valve failed a post fire test and was subsequently replaced. D0002-403 (Press - Fuel Pump Inlet) was overpressurized at J-2 engine cutoff.

One measurement used for hardwire monitoring failed during mainstage operation. This actually constitutes a flight measurement failure since the hardwire measurement, C0419-403, is the complement to flight measurement C0382-403 (Temp - GOX/GH2 Burner Chamber Dome); C0419-403 was off-scale high during mainstage operation. C0382-403 was not monitored on T/M during the test.

The measurements listed below were susceptible to the high RF field experienced on the Complex Beta test stand. The RFI condition was exhibited as noise or data shift, or both, when comparing open and closed loop RF data. RFI responses have been observed during previous firings; this problem does not exist when the stage is in the launch vehicle configuration. No action is being contemplated to remedy the problem.

C0197-401	Temperature - Primary Instrumentation Package
M0060-411	Volt - PU Valve Control
M0068-411	Volt - 5-Volt Excitation Module, Forward 2
N0018-411	Misc - PCM/FM Transmitter Output Power
N0055-411	Misc - Telemetry RF System Reflected Power, Channel 1
N0060-411	Misc - Operational Telemetry RF Transmitter Power Kit
N0061-411	Misc - Operational Telemetry Reflected RF Power Kit
N0063-411	Misc - PU Oven Stability Monitor
D0104-403	Press - LH_2 Pressurization Module Inlet

RACS calibrations were evaluated for proper levels at T - 2424 seconds (1333:20 hours PST) of Phase D (mainstage firing). All measurements were within the acceptable RACS levels except N0055-411 (PCM/FM Reflected Power) which was confirmed as an RFI problem.

Comparison of the T/M and GIS hardwire data was conducted during the Sacramento test facility evaluation. A total of 48 measurements were compared with satisfactory results. The comparison results are shown in table 12-4.

12.2 Telemetry Subsystem Performance

The telemetry subsystem performance was good. There was no loss of system synchronization, and good data were received from all channels. DDAS hardwire (600Hz) to T/M (open loop RF) comparison did not reveal any data discrepancies.

Response of the telemetry subsystem to in-flight multiplexer calibrations were evaluated during Phase D at the following times: T_0 + 116 seconds and T_0 + 1219 seconds. The chilldown pumps and the auxiliary hydraulic pumps were operating at T_0 + 116 seconds and not operative at T_0 + 1219 seconds. All calibration levels during both evaluation periods were within the tolerance of ±8 bit counts out of a range of 24 to 999 bits.

12.3 RF Subsystem Performance

The RF subsystem performance was satisfactory. A single sideband transmitter was installed on the stage. During open loop operation the RF power measurements were susceptible to the RF field; therefore, proper assessment of the RF system could not be accomplished. For worst case using the closed-loop power output and the open-loop reflected power, the PCM/FM VSWR was 1.70:1, and the SSB/FM VSWR was 1.55:1.

The following table presents the PCM/FM and SSB transmitter output power and VSWR data for open- and closed-loop operation.

RF Subsystem Data

System	Open-Loop Value*	Closed-Loop Value
PCM/FM Transmitter Output Power (minimum acceptable is 15 W)	20.3	19.7
VSWR (maximum acceptable is 1.8:1)	1.70:1	1.60:1
SSB/FM Transmitter Output Power (minimum acceptable is 15 W)	20.9	20.3
VSWR (maximum acceptable is 1.8:1)	1.55:1	1.21:1

*RF measurements were susceptible to RFI

12.4 Electromagnetic Compatibility

The data acquisition system did not interfere with other stage systems in the areas of electromagnetic compatibility. However, measurements did exhibit data shift and noise caused by the susceptibility to the high RF field experienced on the Complex Beta test stand. See paragraph 12.1 for the complete listing.

12.5 Emergency Detection System Measurements

Measurements D0177-408 (Press - LH_2 Tank Ullage, EDS No. 1), D0178-408 (Press - LH_2 Tank Ullage, EDS No. 2), D0179-406 (Press - LOX Tank Ullage EDS No. 1), and D0180-406 (Press - LOX Tank Ullage, EDS No. 2) all performed satisfactorily.

12.6 Hardwire Data Acquisition System Performance

The ground instrumentation system (GIS) provides a backup and data comparison for certain stage telemetry system parameters in addition to recording measurements from the ground support and facility equipment.

The GIS also provides stripcharts for redline and cutoff-parameter monitoring. The GIS performance during acceptance firing was satisfactory.

The following table presents the type of recording equipment and the number of channels used.

Ground Recorder	Channels Assigned
Beckman 210 Digital Data System	176
Constant Bandwidth FM	63
Wideband FM	7
Stripcharts	36
Total	282

Table 12-5 presents a list of the various types of measurement data recorded and the performance of the system.

12.6.1 Hardwire Measurement Discrepancies

There were four measurement failures, yielding an overall hardwire measurement efficiency of 99.5 percent. Measurement discrepancies that occurred during the acceptance firing are listed in table 12-6.

TABLE 12-1

TELEMETRY SYSTEM PERFORMANCE SUMMARY

FUNCTION	NUMBER ASSIGNED PER IP&CL	INACTIVE**	NET ACTIVE	DISCREPANCIES	FAILURES	PERFORMANCE* (percent)
Acceleration (A)	0	-	-	-	-	-
Acoustic (B)	12	10	2	-	-	-
Temperature (C)	61	18	43	1	1	97.7
Pressure (D)	79	24	55	1	1	98.2
Vibration (E)	3	3	0	-	-	-
Flow (F)	4	0	4	0	0	100.0
Position (G)	8	5	3	0	1	66.7
Events (K)	71	4	67	0	0	100.0
Liquid Level (L)	7	1	6	0	0	100.0
Volt/Current/Freq (M)	38	2	36	2	0	100.0
Miscellaneous (N)	11	0	11	5	0	100.0
Strain (S)	0	-	-	-	-	-
Speed (T)	2	0	2	0	0	100.0
TOTAL	296	67	229	9	3	98.7 percent

$$\text{*Performance (percent)} = \frac{\text{Net Active - Failures}}{\text{Net Active}} \times 100$$

**See Table 12-3 T/M Measurement Status

TABLE 12-2

TELEMETRY MEASUREMENT ANOMALIES

MEASUREMENT NO.	PARAMETER	REMARKS
C0382-403	Temp - Burner Chamber Dome	This measurement used for hardwire monitoring failed at T + 925 seconds, 414 seconds into the mainstage burn. The sensor failed in the open circuit mode and failure was caused by stage vibrations. After extensive analysis conducted with the vendor (Rosemount), a weld fracture was discovered between the sensor element and the probe lead wire. Corrective action is being implemented by the vendor.
D0002-403	Press - LH_2 Pump Inlet	The measurement failed at engine cutoff. The data abruptly increased to off-scale-high and subsequently remained in that condition. A calibration check on the transducer has shown that it exhibited a permanent 100% output voltage, indicating that it was in the off-scale-high mode. The malfunction was the result of an excessive pressure transient at the pump inlet at engine cutoff. This measurement has failed on previous acceptance tests due to similar pressure transients.
G0010-401	Position - P.U. System Ratio Valve	The measurement was qualified as good, but the valve exhibited erratic operation on the acceptance firing data. It was removed post fire and tested per ECP J2-666 R1 Mod. Instruction R5436.666. The valve failed this test and was replaced.

TABLE 12-2 (Continued)

TELEMETRY MEASUREMENT ANOMALIES

MEASUREMENT NO.	PARAMETER	REMARKS
N0018-411 N0055-411 N0060-411 N0061-411	Misc - PCM/FM Transmitter Output Misc - T/M RF System Reflected Power Misc - Operational T/M Transmitter Output Power Misc - Operational T/M Reflected Power	These measurements were susceptible to the high RF environment experienced on the Beta test stand. Data shifts were observed when the RF system was switched from open to closed-loop operation. The RACS level differences of open and closed loop also confirmed the RFI. N0055-411 and N0061-411 are more susceptible because of their sensitivity in the operating range and include actual changes in reflected power as well as RFI changes. The data shifts for N0055-411 and N0061-411 were -10% and -13% respectively.
C0197-401 M0068-411 N0063-411	Temp - Primary Instrumentation Package Volt - SV Excitation Module, Fwd 2 Misc - PU Oven Stability Monitor	These measurements indicated a shift in data level when the RF system was switched from open to closed-loop operation. All RFI data shifts were below the RFI criterion. The data shifts from open to closed-loop were: C0197-401, +1%; M0068-411, +1%; M0063-411, + 1/2%.
D0104-403	Press - LH_2 Press Module Inlet	The RACS calibration level was observed to drift positively from Phase G (burner firing) to Phase D (mainstage firing). The drift was 1% on high and 2% on low RACS levels in approximately 3-1/2 hours. This drift is not significant; however, subsequent drifting of this magnitude could cause an out-of-tolerance condition.
M0060-411	Volt - PU Valve Control	This measurement indicated a shift in data level of +2% when the RF system was switched from open to closed-loop operation. The data shift is within the system EMI criteria.

TABLE 12-3

INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
B0028-402	Acous - Sta 2548	Simulated, aft interstage not installed
B0029-402	Acous - Sta 2574	Simulated, aft interstage not installed
B0030-402	Acous - Sta 2589	Simulated, aft interstage not installed
B0031-402	Acous - Sta 2711	Simulated, aft interstage not installed
B0032-402	Acous - Sta 2733	Simulated, aft interstage not installed
B0033-402	Acous - Sta 2529	Simulated, aft interstage not installed
B0034-402	Acous - Sta 2554	Simulated, aft interstage not installed
B0035-402	Acous - Sta 2589	Simulated, aft interstage not installed
B0036-402	Acous - Sta 2726	Simulated, aft interstage not installed
B0038-404	Acous - Sta 2784 (Between 98-99 Ext)	Deleted because of damaged transducer
*C0003-403	Temp - Fuel Pump Inlet	C0003-403 was connected to element "B" of the dual element probe in place of C0648, equivalent hardwire measurement, to provide greater accuracy in center of flow for redline monitoring
C0007-401	Temp - Engine Control Helium	Simulated, APS not installed
C0021-415	Temp - Attitude Control Fuel Module 2	Simulated, APS not installed
C0022-415	Temp - Attitude Control Oxid Module 2	Simulated, APS not installed
C0023-414	Temp - APS Helium Pressure Tank, Module 1	Simulated, APS not installed
C0050-401	Temp - Hydraulic Pump Inlet Oil	Open, H/W requirement
C0102-411	Temp - Forward Battery No. 1	Simulated, primary battery not used
C0103-411	Temp - Forward Battery No. 2	Simulated, primary battery not used

*This measurement installed in variance with IP&CL configuration.

TABLE 12-3 (Continued)

MEASUREMENT NO.	PARAMETER	REMARKS
C0104-404	Temp - Aft Battery No. 1	Simulated, primary battery not used
C0105-404	Temp - Aft Battery No. 2	Simulated, primary battery not used
C0131-404	Temp - Aft Battery No. 1, Unit 2	Simulated, primary battery not used
C0132-414	Temp - Attitude Control Oxid, Module 1	Simulated, APS not installed
C0136-414	Temp - Attitude Control Fuel, Module 1	Simulated, APS not installed
C0187-415	Temp - APS Helium Press Tank Module 2	Simulated, APS not installed
C0200-401	Temp - Fuel Inj.	Open, H/W requirement
C0211-411	Temp - Fwd Battery No. 1, Unit 2	Simulated, primary battery not used
C0212-404	Temp - Aft Battery No. 2, Unit 2	Simulated, primary battery not used
C0382-403	Temp - O_2-H_2 Burner Chamber Dome	Open, H/W requirement
D0027-414	Press - Attitude Control, Chamber 1-1	Simulated, APS not installed
D0028-414	Press - Attitude Control, Chamber 1-2	Simulated, APS not installed
D0029-414	Press - Attitude Control, Chamber 1-3	Simulated, APS not installed
D0030-415	Press - Attitude Control, Chamber 2-1	Simulated, APS not installed
D0031-415	Press - Attitude Control, Chamber 2-2	Simulated, APS not installed
D0032-415	Press - Attitude Control, Chamber 2-3	Simulated, APS not installed
D0035-414	Press - Attitude Control, Helium Pressure Tank 1	Simulated, APS not installed
D0036-415	Press - Attitude Control, Helium Pressure Tank 2	Simulated, APS not installed
D0037-414	Press - Helium Reg. Outlet, Module 1 (APS)	Simulated, APS not installed
D0038-415	Press - Helium Reg. Outlet, Module 2 (APS)	Simulated, APS not installed
D0041-403	Press - Hydraulic System	Open, H/W requirement

TABLE 12-3 (Continued)

MEASUREMENT NO.	PARAMETER	REMARKS
D0042-403	Press - Reservoir Oil	Open, H/W requirement
D0070-414	Press - Fuel Supply Manifold, Module 1	Simulated, APS not installed
D0071-414	Press - Oxid Supply Manifold, Module 1	Simulated, APS not installed
D0072-415	Press - Fuel Supply Manifold, Module 2	Simulated, APS not installed
D0073-415	Press - Oxid Supply Manifold, Module 2	Simulated, APS not installed
D0097-414	Press - Fuel Tank Ullage Volume, Module 1	Simulated, APS not installed
D0098-414	Press - Oxid Tank Ullage Volume, Module 1	Simulated, APS not installed
D0099-415	Press - Fuel Tank Ullage Volume, Module 2	Simulated, APS not installed
D0100-415	Press - Oxid Tank Ullage Volume, Module 2	Simulated, APS not installed
D0220-414	Press - Ullage Control, Chamber 1-4	Simulated, APS not installed
D0221-415	Press - Ullage Control, Chamber 2-4	Simulated, APS not installed
D0250-414	Press - APS Helium Press, Tk 1	Simulated, APS not installed
D0251-415	Press - APS Helium Press, Tk 2	Simulated, APS not installed
E0219-402	Vib - Aft I/S Edge of 70 Norm	Open, aft I/S not installed
E0220-402	Vib - Aft I/S Bet 70-71 Norm	Open, aft I/S not installed
E0221-402	Vib - Aft I/S Edge of 71 Norm	Open, aft I/S not installed
G0003-401	Position - Main LOX Valve	Simulated, H/W requirement
G0004-401	Position - Main Fuel Valve	Simulated, H/W requirement
G0005-401	Position - Gas Generator Valve	Simulated, H/W requirement
G0008-401	Position - LOX Turbine Bypass Valve	Simulated, H/W requirement
G0009-401	Position - GH_2 Start Tank Valve	Simulated, H/W requirement
K0020-401	Event - ASI LOX Valve Open	Open, computer requirement

TABLE 12-3 (Continued)

MEASUREMENT NO.	PARAMETER	REMARKS
K0126-401	Event - LOX Bleed Valve Closed	Open, computer requirement
K0127-404	Event - LH_2 Bleed Valve Closed	Open, computer requirement
K0152-404	Event - Rate Gyro Wheel Speed OK	Simulated, rate gyro not installed
L0007-403	Level - Reservoir Oil	Simulated, H/W requirement
M0073-404	Voltage - O_2-H_2 Burner Spark Exciter - 2	Open, computer requirement
M0074-404	Voltage - O_2-H_2 Burner Spark Exciter - 1	Open, computer requirement

TABLE 12-4

TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +571 sec)

PARAMETER	UNITS	TELEMETRY		HARDWIRE		
		MEAS NO.	PCM	MEAS NO.	GIS	F/M
Temp - LH_2 Turbine Inlet	deg R	C0001	1,599	C0755	1,558	1,560
Temp - LH_2 Pump Inlet	deg R	C0003	37.6	C0658	37.5	37.2
Temp - LOX Pump Inlet	deg R	C0004	164.4	C0659	164.2	164.1
Temp - GH_2 Start Bottle	deg R	C0006	214	C0649	221	--
Temp - Electrical Control Assembly	deg R	C0011	510	C0657	510	--
Temp - Gas Generator Fuel Bleed Valve	deg R	C0012	53.9	C0650	53.6	--
Temp - LOX Pump Discharge	deg R	C0133	169.5	C0648	169.6	169.6
Temp - LH_2 Pump Discharge	deg R	C0134	51.5	C0644	51.5	51.4
Temp - Thrust Chamber Jacket	deg R	C0199	136	C0645	150	--
Temp - Cold Helium Sphere No. 4	deg R	C0210	29.0	C0661	36.4	--
Press - Thrust Chamber	psia	D0001	785	D0524	811	--
Press - LH_2 Pump Inlet	psia	D0002	30.6	D0536	31.7	31.7
Press - LOX Pump Inlet	psia	D0003	41.9	D0537	42.7	42.2
Press - Main LH_2 Injector	psia	D0004	872	D0518	865	875
Press - LH_2 Pump Discharge	psia	D0008	1,215	D0516	1,237	1,260
Press - LOX Pump Discharge	psia	D0009	1,053	D0522	1,059	1,065
Press - Gas Generator Chamber	psia	D0010	680	D0530	660	665
Press - Control Helium Reg. Discharge	psia	D0014	565	D0581	578	585
Press - GH_2 Start Bottle	psia	D0017	1,199	D0525	1,195	1,200
Press - Engine Reg. Outlet	psia	D0018	411	D0535	410	--
Press - Engine Control He Sphere	psia	D0019	2,853	D0534	2,864	--
Press - LH_2 Repress Sphere	psia	D0020	2,891	D0513	2,924	--
Press - LOX Turbine Outlet	psia	D0086	32.0	D0533	32.7	--
Press - LOX Repress Sphere	psia	D0088	2,889	D0512	2,914	--
Press - LH_2 Tank Ullage	psia	D0177	31.9	D0539	32.5	--
Press - LH_2 Tank Ullage	psia	D0178	32.1	D0539	32.5	--
Press - LOX Tank Ullage EDS 1	psia	D0179	39.6	D0540	40.0	--

TABLE 12-4 (Continued)

TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +571 sec)

PARAMETER	UNITS	TELEMETRY MEAS NO.	TELEMETRY PCM	HARDWIRE MEAS NO.	HARDWIRE GIS	HARDWIRE F/M
Press - LOX Tank Ullage EDS 2	psia	D0180	40.3	D0540	40.0	--
Press - Ambient Helium Sphere	psia	D0236	2,873	D0541	2,915	--
Press - Common Bulkhead Internal	psia	D0237	0.0	D0545	0.0	--
Press - Cold Helium Sphere	psia	D0261	2,234	D0542	--	--
Flowrate - LOX	gpm	F0001	2,888	F0506	2,879	2,879
Flowrate - LH_2	gpm	F0002	7,933	F0507	7,848	7,843
Position - Pitch Actuator	deg	G0001	0.0	G0504	0.1	0.0
Position - Yaw Actuator	deg	G0002	0.0	G0505	0.0	0.0
Position - PU Valve	deg	G0010	29.5	G0503	29.5	29.5
Voltage - Engine Control Bus	vdc	M0006	28.3	M0514	28.3	28.3
Voltage - Engine Ignition Bus	vdc	M0007	28.6	M0515	28.5	28.4
Voltage - Aft Battery 1	vdc	M0014	27.9	M0541	28.6	28.4
Voltage - Aft Battery 2	vdc	M0015	56.8	M0540	56.5	56.5
Voltage - Fwd Battery 1	vdc	M0016	28.1	M0543	28.3	29.0
Voltage - Fwd Battery 2	vdc	M0018	27.3	M0542	27.7	28.0
Current - Fwd Battery 1	amp	M0019	16.5	M0731	18.3	18.7
Current - Fwd Battery 2	amp	M0020	4.7	M0732	4.5	4.7
Current - Aft Battery 1	amp	M0021	12.0	M0733	13.0	12.5
Current - Aft Battery 2	amp	M0022	47.0	M0734	48.0	48.0
Speed - LOX Pump	rpm	T0001	8,577	T0502	8,604	8,605
Speed - LH_2 Pump	rpm	T0002	26,798	T0503	26,716	26,695

TABLE 12-5

HARDWIRE DATA ACQUISITION SYSTEM

MEASUREMENT TYPE	RECORDED	DISCREPANCIES*	SUCCESSFUL (percent)
Pressure	96	1	98.9
Temperature	46	2	95.6
Flow	2	0	100.0
Position	10	0	100.0
Voltage-Current	19	0	100.0
Events	674	1	99.9
Speed	2	0	100.0
Level	1	0	100.0
Vibration	5	0	100.0
Miscellaneous	2	0	100.0
TOTAL	857	4	99.5 percent

*A data discrepancy does not necessarily mean that no data were gathered for this measurement. Refer to table 12-6 for a description of the problem.

TABLE 12-6

HARDWIRE MEASUREMENT DISCREPANCIES

MEASUREMENT NO.	PARAMETER	REMARKS
C0654-401	Temp - Fuel Pump Turbine Outlet	The hardwire measurement C0654-401 exhibited up to 5% noise on the FM data.
C0715-B03	Temp - Upstream Fluid Facility Metering Orifice	The measurement had up to 3% noise on the digital data.
D0577-406	Press - Oxidizer Tank Ullage, Umbilical	This is a flight transducer (landline) that will give data up to liftoff. The measurement failed at T_0 + 925 seconds.
K0676-411	Event - LH_2 Fast Fill Sensor Wet Condition On	When switch selector channel 17, P.U. Mixture Ratio 4.5 to 1 ON Command was sent at 11:25:08.481 and 14:28:06.169, K0676-411 LH_2 Fast Fill Sensor exhibited a momentary ON-OFF cycle of 1 and 3 ms, respectively.

SECTION 13

ELECTRICAL POWER AND CONTROL SYSTEMS

13. ELECTRICAL POWER AND CONTROL SYSTEMS

13.1 Electrical Control System

The operational integrity of the electrical control system was verified through the evaluation of the sequence of events records from the digital events recorder (DER) and the PCM flight measurement events data (section 5). The switch selector and sequencer operated properly in sending all control commands to the stage, and all of the commands were received in the stage.

13.1.1 J-2 Engine Control System

All measurements verified that the engine control system responded properly to the engine start and cutoff commands. The sequence of events (section 5) lists the engine firing events and response times.

13.1.2 Secure Range Safety Command System

The secure range safety command system was tested during the engine burn phase to verify the capability of engine cutoff and propellant dispersion. Evaluation of the data showed that the arm and engine cutoff (ECO) and propellant dispersion (P/D) commands were received, and that the EBW firing units (F/U) discharged into their respective pulse sensors. The following measurements were evaluated for system performance:

K0141-411	Event - R/S 1 EBW Pulse Sensor Indication
K0142-411	Event - R/S 2 EBW Pulse Sensor Indication
*K0650-411	Event - P/D EBW F/U 1 Power On
*K0651-411	Event - P/D EBW F/U 2 Power On
*K0659-411	Event - R/S 2 Arm and ECO Command Received
*K0660-411	Event - R/S 1 Arm and ECO Command Received
*K0678-411	Event - R/S 2 Receiver Power On
*K0679-411	Event - R/S System 2 Off Command Received

*Hardwire Measurement.

*K0680-411	Event - R/S 1 Receiver Power On
*K0681-411	Event - R/S 1 Off Command Received
*K0692-404	Event - R/S 2 EBW Arm and Cutoff Command On
*K0693-404	Event - R/S 1 EBW Arm and Cutoff Command On
M0030-411	Volts - R/S 1 EBW Firing Unit
M0031-411	Volts - R/S 2 EBW Firing Unit
N0057-411	Misc - R/S 1 Low Level Signal Strength
N0062-411	Misc - R/S 2 Low Level Signal Strength
*K5757-B03	Event - R/S Tone 1/Propellant Dispersion Command
*K5758-B03	Event - R/S Tone 2/EBW Arm and ECO Command
*K5759-B03	Event - R/S Tone 6/System Off Command
K2404-411	Event - R/S 1 Propellant Dispersion Command Received
K2405-411	Event - R/S 2 Propellant Dispersion Command Received

13.1.3 Control Pressure Switches

A review of the event and pressure measurements associated with the following pressure switches verified that each switch functioned properly during the acceptance firing test. Following is a list of the measurements used for each respective pressure switch verification.

a. LOX Tank Ground Fill Valve Control, Prepress, Flight Control, and Repress Pressure Switch

K0102-404	Event - LOX Prepress and Flight Control Switch - Energized
*K0563-404	Event - LOX Prepress and Flight Control Switch - Energized
K0108-404	Event - LOX Prepress Flight Switch - De-energized
D0179-406	Pressure - LOX Tank Ullage EDS 1
D0180-406	Pressure - LOX Tank Ullage EDS 2
*K0571-404	Event - Cold He SOV Energized - Indication
*K0444-403	Event - LOX Tank Repress Valve - Energized

b. LOX Tank Repress Regulator Backup Pressure Switch

*K0444-403	Event - LOX Tank Repress Valve - Energized
D0228-403	Pressure - LOX/LH_2 Burner LOX Press Coil

*Hardwire Measurement

h. LOX Tank Regulator Backup Pressure Switch

K0156-404	Event - LOX Tank Regulator Backup Pressure Switch - Energized
*K0571-404	Event - LOX Tank Cold He SOV Energized - Indication
D0105-403	Pressure - LOX Tank Pressurization Module He Gas

13.1.4 Vent Valves

The following measurements verified the satisfactory operation of the LOX and LH_2 tank vent valves, and the LH_2 tank directional valve:

K0001-410; *K0532-410	Event - Fuel Tank Vent Valve 1 - Closed
K0017-410; *K0542-410	Event - Fuel Tank Vent Valve 1 - Open Talkback
K0002-424; *K0533-424	Event - Oxid. Tank Vent Valve 1 - Closed
K0016-404; *K0543-404	Event - Oxid. Tank Vent Valve 1 - Open Talkback
K0113-411	Event - LH_2 Tank Directional Vent Valve C - Closed
K0114-411	Event - LH_2 Tank Directional Vent Valve D - Closed

13.1.5 Chilldown Shutoff Valves

The LOX and LH_2 chilldown shutoff valves responded properly to commands as verified by the following measurements:

K0136-409; *K0551-409	Event - LH_2 Chilldown Shutoff Valve - Closed
K0137-409; *K0544-409	Event - LH_2 Chilldown Shutoff Valve - Open Talkback
K0139-424; *K0552-424	Event - LOX Chilldown Shutoff Valve - Closed
K0138-424; *K0545-424	Event - LOX Chilldown Shutoff Valve - Open Talkback

*Hardwire Measurement.

c. LH_2 Tank Repress Regulator Backup Pressure Switch

*K0443-403	Event - LH_2 Tank Repress Valve - Energized
D0231-403	Pressure - GOX/GH_2 Burner LH_2 Press Coil

d. Control (Ambient) Helium Regulator Backup Pressure Switch

D0014-403	Pressure - Control Helium Regulator, Discharge

e. LH_2 Ground Fill Valve Control, Prepress, Flight Control, and Step-Pressure Switch

K0184-404	Event - LH_2 Flight Control Pressure Switch - Energized
*K0616-404	Event - LH_2 Tank Prepressurization Pressure Switch - Energized
K0101-404	Event - LH_2 Repress Control Switch - De-energized
*K0582-404	Event - LH_2 Tank Repress Pressure Switch - On
*K0524-404	Event - LH_2 Tank Flight Pressure Valve - Energized
*K0523-404	Event - LH_2 Tank Step-Pressure Valve - Energized
D0177-408	Pressure - LH_2 Tank Ullage EDS 1
D0178-408	Pressure - LH_2 Tank Ullage EDS 2

f. LH_2 Tank Repress Pressure Switch

K0101-404	Event - LH_2 Repress Control Switch - De-energized
*K0582-404	Event - LH_2 Tank Repress Pressure Switch - On
*K0443-403	Event - LH_2 Tank Repress Valve - Energized
D0177-408	Pressure - LH_2 Tank Ullage EDS 1
D0178-408	Pressure - LH_2 Tank Ullage EDS 2

g. Engine Pump Purge Control Module Pressure Switch

K0105-404	Event - Pump Purge Regulator Backup - De-energized
*K0456-404	Event - Seal Pump Purge Control Regulator Backup Pressure Switch - De-energized
*K0566-404	Event - Engine Pump Purge Control Module Solenoid Valve - Energized
D0050-403	Pressure - Engine Pump Purge Regulator Pressure

*Hardwire Measurement.

13.1.6 Fill and Drain Valves (Fuel and LOX)

A review of the following events showed that the LOX and LH_2 fill and drain valves operated according to the GSE commands issued.

K0003-427; *K0554-404	Event - LH_2 Tank Fill and Drain Valve - Closed
*K0546-404	Event - LH_2 Tank Fill and Drain Valve - Open Talkback
K0003-427; *K0553-404	Event - LOX Tank Fill and Drain Valve - Closed
*K0547-404	Event - LOX Tank Fill and Drain Valve - Open Talkback

13.1.7 Depletion Sensors

A review of the following measurements showed that the LOX and LH_2 depletion sensors performed satisfactorily, and no anomalies were observed during the test:

*K0601-406	Event - LOX Depletion Sensor No. 1 - Wet
*K0602-406	Event - LOX Depletion Sensor No. 2 - Wet
*K0603-406	Event - LOX Depletion Sensor No. 3 - Wet
*K0449-404	Event - LOX Depletion Sensor No. 4 - Wet
*K0597-408	Event - LH_2 Depletion Sensor No. 1 - Wet
*K0598-408	Event - LH_2 Depletion Sensor No. 2 - Wet
*K0599-408	Event - LH_2 Depletion Sensor No. 3 - Wet
*K0450-411	Event - LH_2 Depletion Sensor No. 4 - Wet

13.2 Auxiliary Propulsion System (APS) Electrical Control System

The APS simulators, Model DSV-4B-188B, were used during the acceptance firing to verify the APS-stage interface control functions. The APS pitch and yaw program, which is monitored by measurements K0133-404 and K0135-404, was not exercised during this firing. This was due to the fact that the nonprogrammed engine cutoff caused a deviation from the normal acceptance firing sequence.

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*Hardwire Measurement.

The remaining measurements that were evaluated are listed below:
listed below:

		Specified Min Value (Vdc)	Specified Max Value (Vdc)
K0132-404	Event - APS Eng. 1-1/1-3 Feed Valves Open	3.33	3.46
K0134-404	Event - APS Eng. 2-1/2-3 Feed Valves Open	3.23	3.35

The specified minimum value of 3.2 Vdc indicates that all of the feed valves operated according to commands.

13.3 Electrical Power System

The electrical power system performed satisfactorily throughout the acceptance firing. It supplied power to other stage systems, as required, and the external/internal motor-driven switches functioned properly.

13.3.1 Battery Simulators

Secondary batteries were used to provide internal electrical power during the acceptance firing test. The battery voltage and current levels were measured at the Stage Battery Simulators, Model DSV-4B-727, and these levels remained within their required limits. Figures 13-1 through 13-8 are plots showing the voltage and current levels at the battery simulators during selected phases of the acceptance firing test.

13.3.2 PU Static Inverter Converter

The static inverter converter operated satisfactorily during the O_2-H_2 burner repressurization test and the mainstage firing test. Voltage and frequency levels during the acceptance firing test are given below.

Measurements and Characteristics	Acceptable Limits	Actual Min. Value	Actual Max. Value
M0001-411 Voltage	115.0 $\pm$3.45 Vrms	114.4 Vrms	114.4 Vrms
M0004-411 Voltage	4.9 $\pm$0.2 Vdc	5.06 Vdc	5.07 Vdc
M0023-411 Voltage	21.0 $\pm^{1.5}_{1.0}$ Vdc	22.17 Vdc	22.17 Vdc
M0012-411 Frequency	400.0 $\pm$6.0 Hz	403.7 Hz	403.9 Hz

13.3.3 Chilldown Inverters

The inverters performed satisfactorily during the mainstage firing test and the O_2-H_2 burner repressurization test. The phase voltages and frequencies are listed below.

Measurements and Characteristics	Acceptable Limits	Actual Min. Value	Actual Max. Value
M0027-404 Phase A-B, LOX C/D Inverter	56 ±4 Vac	55.5 Vac	58.0 Vac
M0040-404 Phase A-C, LOX C/D Inverter	56 ±4 Vac	55.5 Vac	58.0 Vac
M0029-404 Frequency LOX C/D Inverter	400 ±10 Hz	399.5 Hz	399.8 Hz
M0026-404 Phase A-B, LH_2 C/D Inverter	56 ±4 Vac	55.0 Vac	58.0 Vac
M0041-404 Phase A-C, LH_2 C/D Inverter	56 ±4 Vac	55.0 Vac	58.0 Vac
M0028-404 Frequency LH_2 C/D Inverter	400 ±10 Hz	399.5 Hz	401.0 Hz

13.3.4 5-Volt Excitation Modules

The forward and aft 5-Volt excitation modules performed as expected during the acceptance firing test. The actual performance values are shown below:

Measurements and Characteristics	Acceptable Limits	Actual Min. Value	Actual Max. Value
M0025-404 Aft Voltage	5.0 ±0.03 Vdc	4.99 Vdc	5.00 Vdc
M0024-411 Forward 1 Voltage	5.0 ±0.03 Vdc	5.00 Vdc	5.00 Vdc
M0068-411 Forward 2 Voltage	5.0 ±0.03 Vdc	4.99 Vdc	5.00 Vdc

13.4 Separation Exploding Bridgewire (Ullage Rocket EBW) System

Since live ordnance is not installed, EBW pulse sensors are used during the acceptance firing to verify the operational integrity of the stage electrical control system in providing the commands necessary to charge, fire, and jettison the ullage rockets. The measurements given below furnished the data used to verify this integrity:

K0149-404	Event - Ullage Rocket Jettison EBW P/S 1 Indication
K0150-404	Event - Ullage Rocket Jettison EBW P/S 2 Indication
K0176-404	Event - Ullage Rocket Ignition EBW P/S 1 Indication
K0177-404	Event - Ullage Rocket Ignition EBW P/S 2 Indication
*K0673-404	Event - Ullage Rocket Pilot Relays Reset
M0064-404	Volts - Ullage Rocket Ignition, EBW F/U 1
M0065-404	Volts - Ullage Rocket Ignition, EBW F/U 2
M0067-404	Volts - Ullage Rocket Jettison, EBW F/U 1
M0068-411	Volts - Ullage Rocket Jettison, EBW F/U 2

13.5 O_2-H_2 Burner

The operation of the O_2-H_2 burner, with respect to the operational integrity of the electrical control system, was normal and no problems were encountered. The sequence of events (section 5) verifies that burner control commands were sent and received, and that instrumentation response and talkback signals occurred as predicted. The voltage and current profiles of the battery simulators during the burner firings are presented in figures 13-5, 13-6, 13-7, and 13-8.

*Hardwire Measurement.

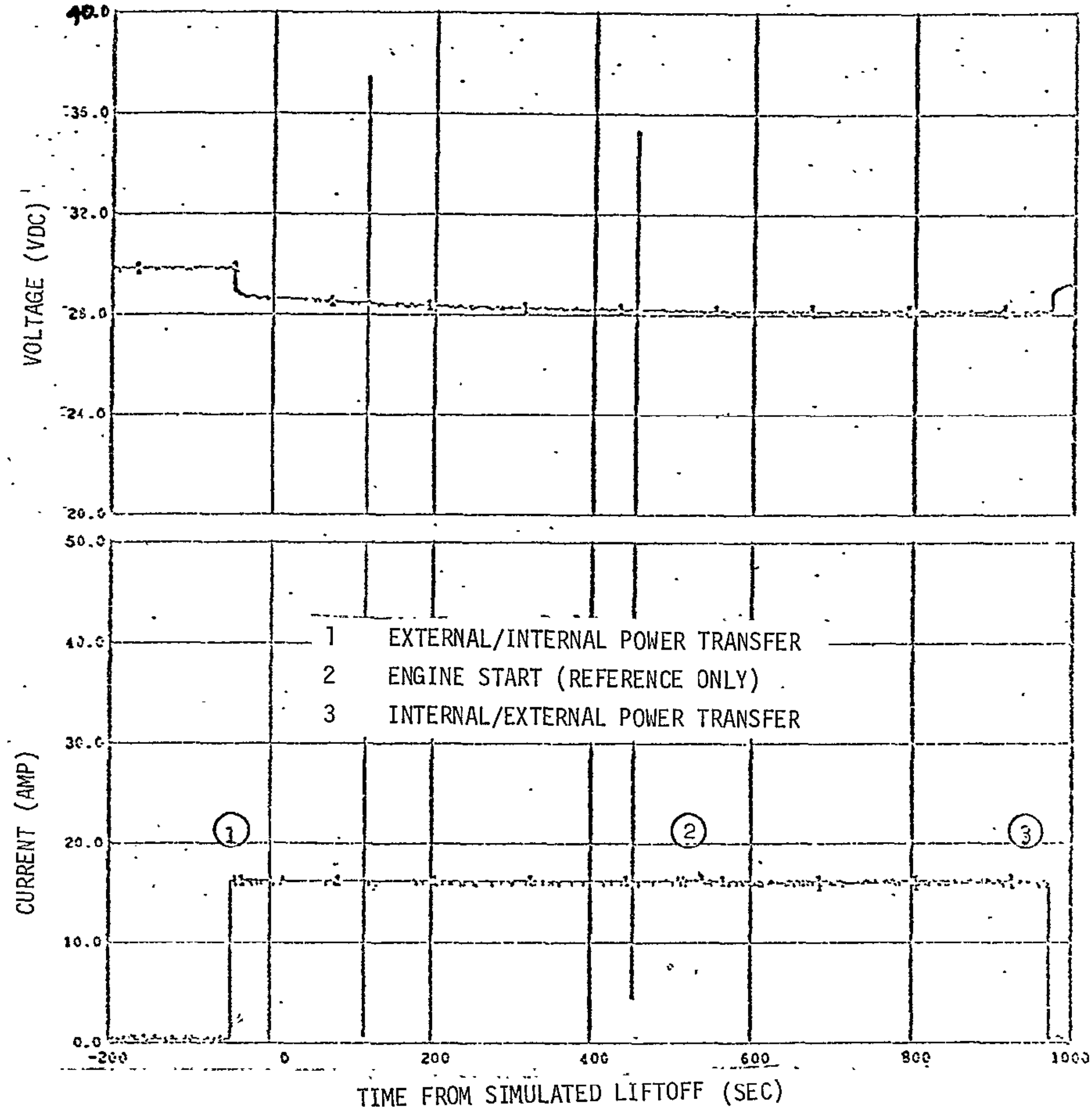

Figure 13-1. Forward Battery No. 1 Profile (Mainstage Firing)

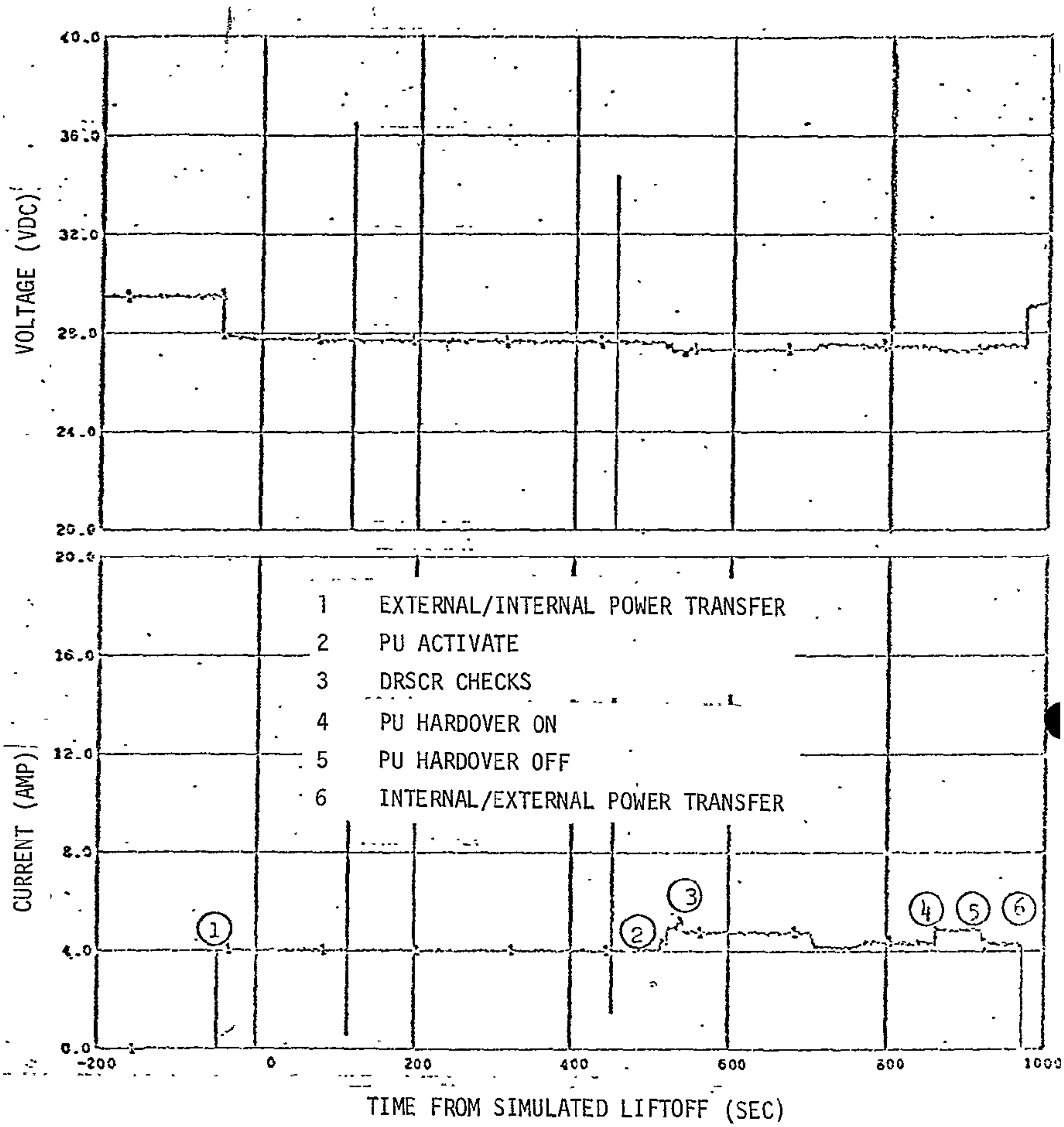

Figure 13-2. Forward Battery No. 2 Profile (Mainstage Firing)

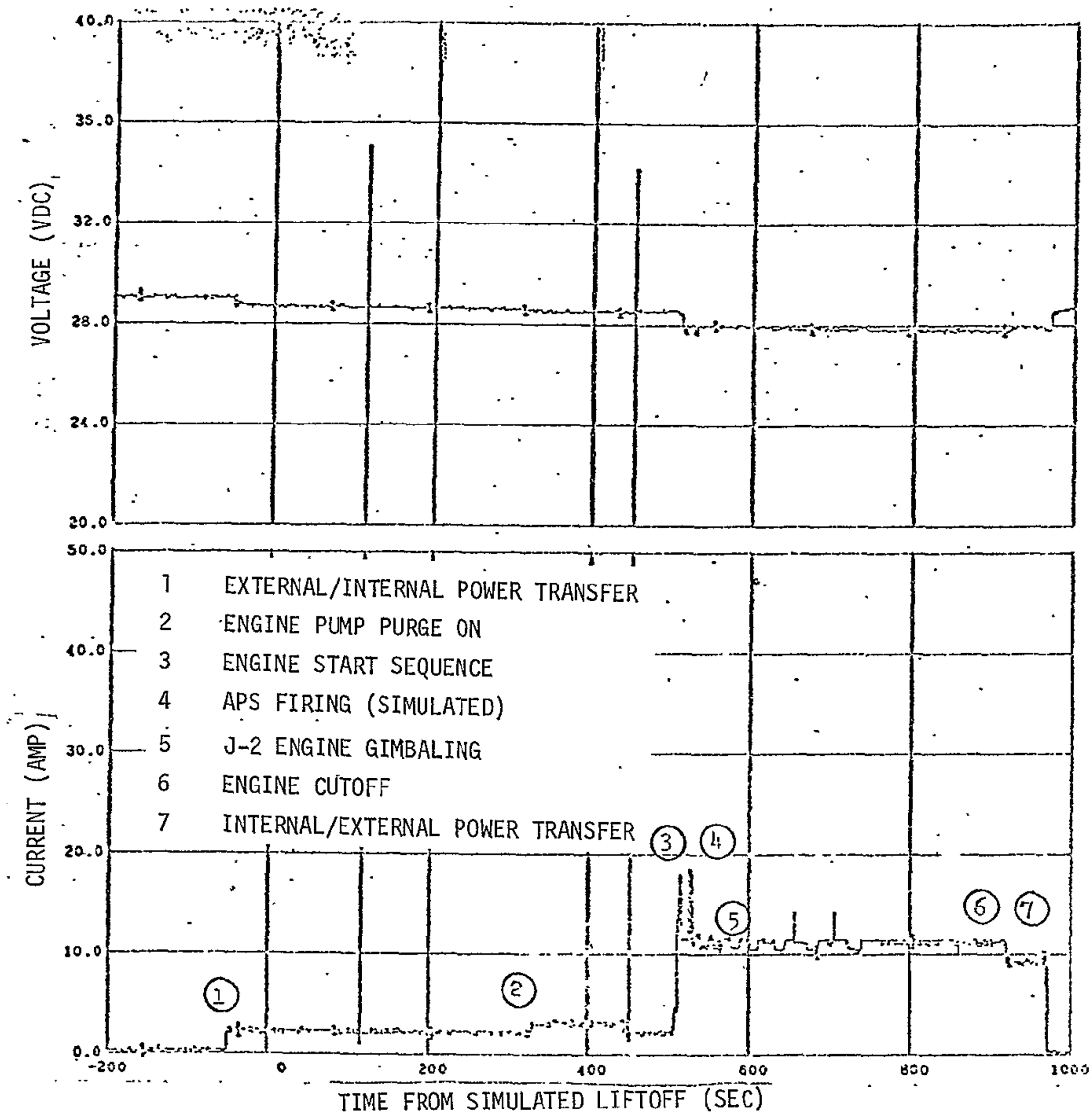

Figure 13-3. Aft Battery No. 1 Profile (Mainstage Firing)

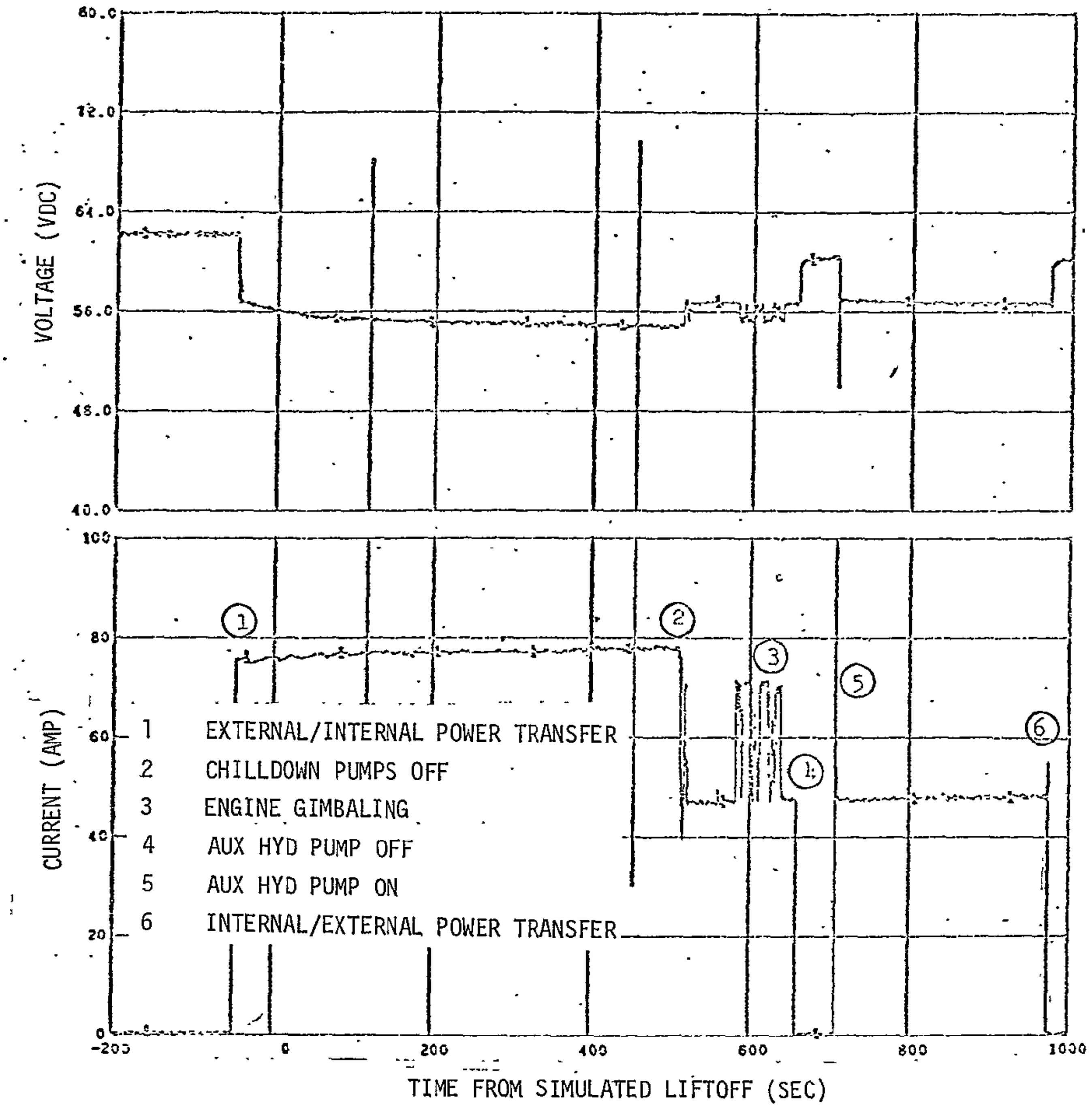

Figure 13-4. Aft Battery No. 2 Profile (Mainstage Firing)

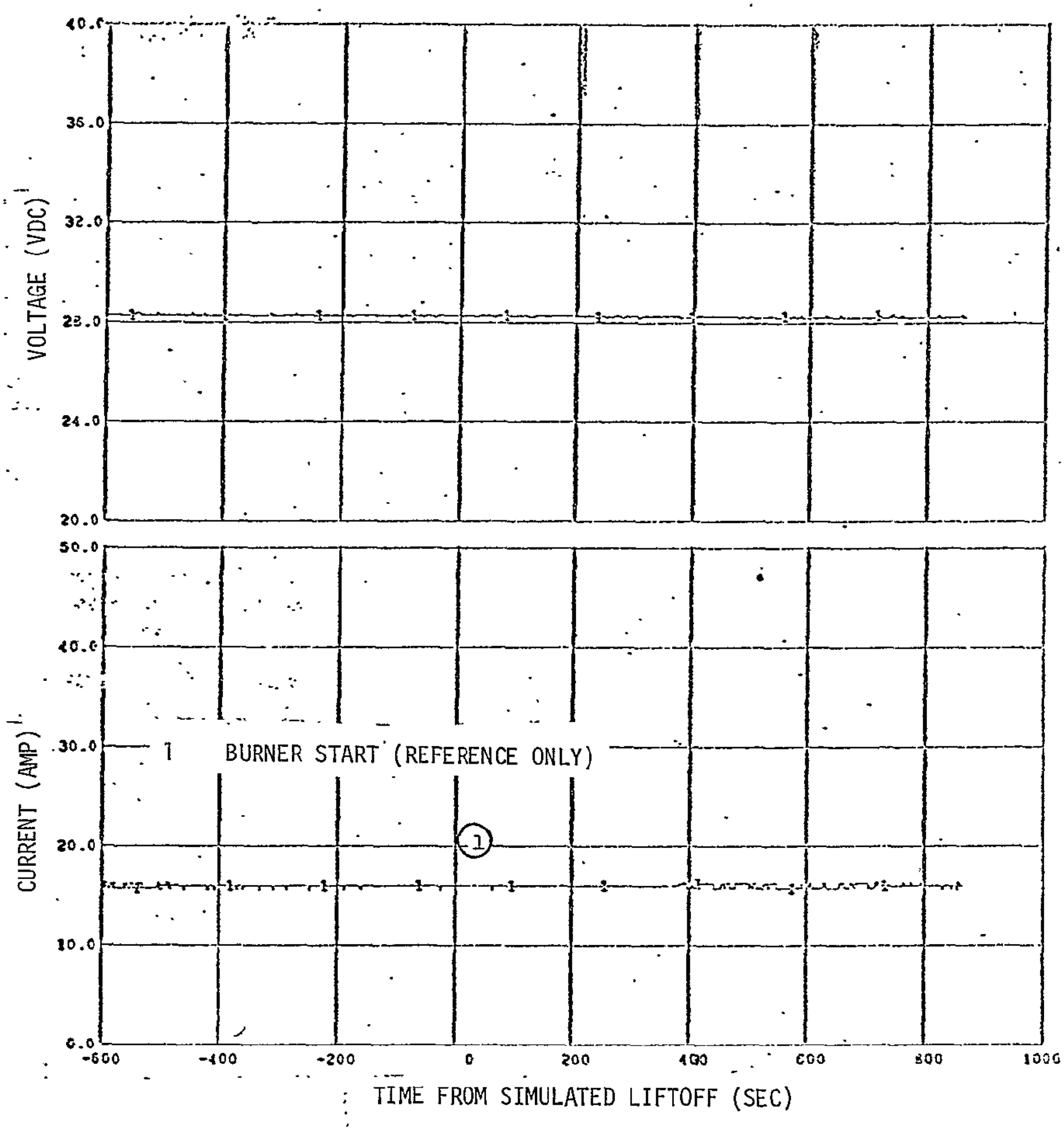

Figure 13-5. Forward Battery No. 1 Profile (O_2-H_2 Burner Firing)

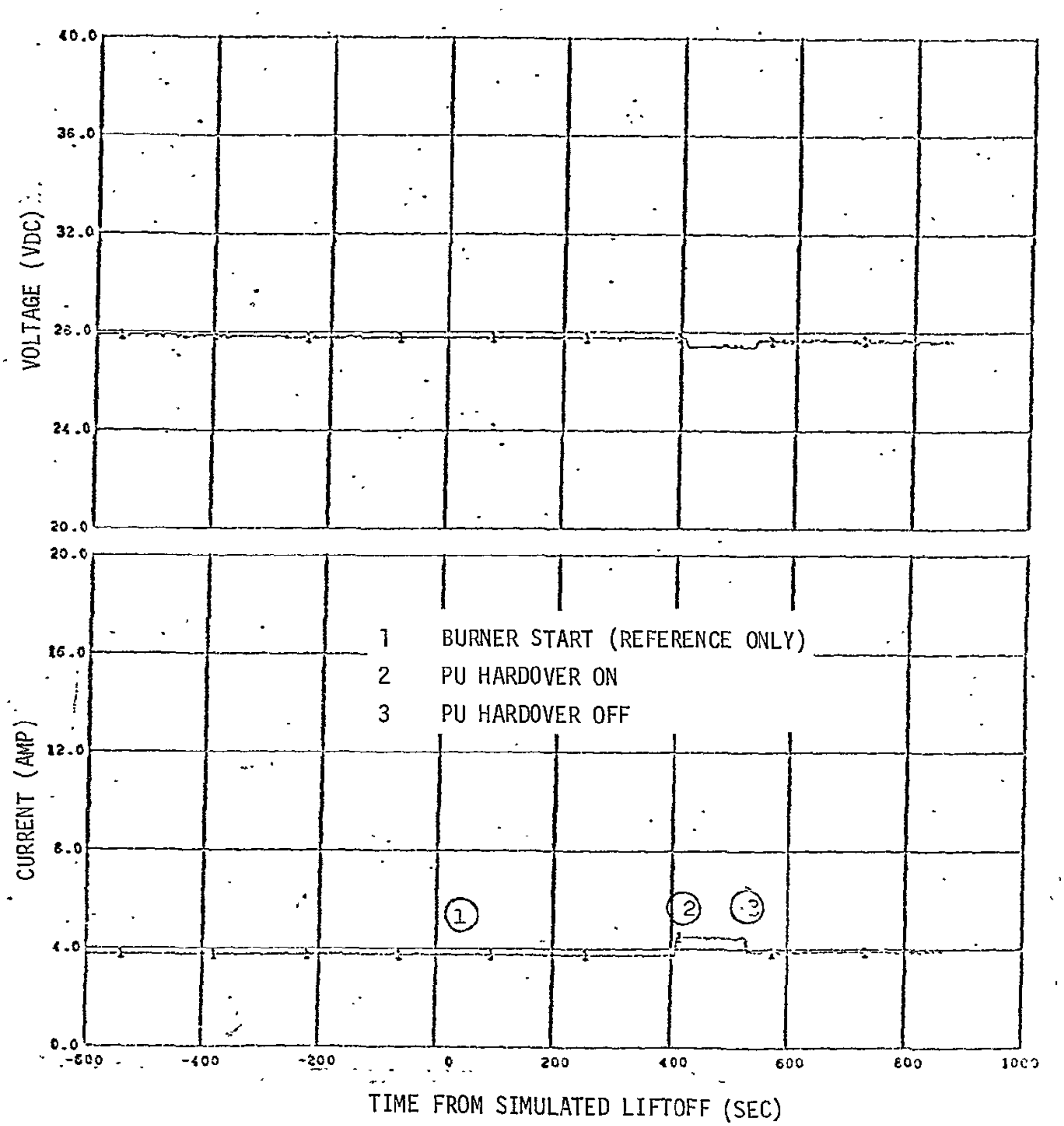

Figure 13-6. Forward Battery No. 2 Profile (O_2-H_2 Burner Firing)

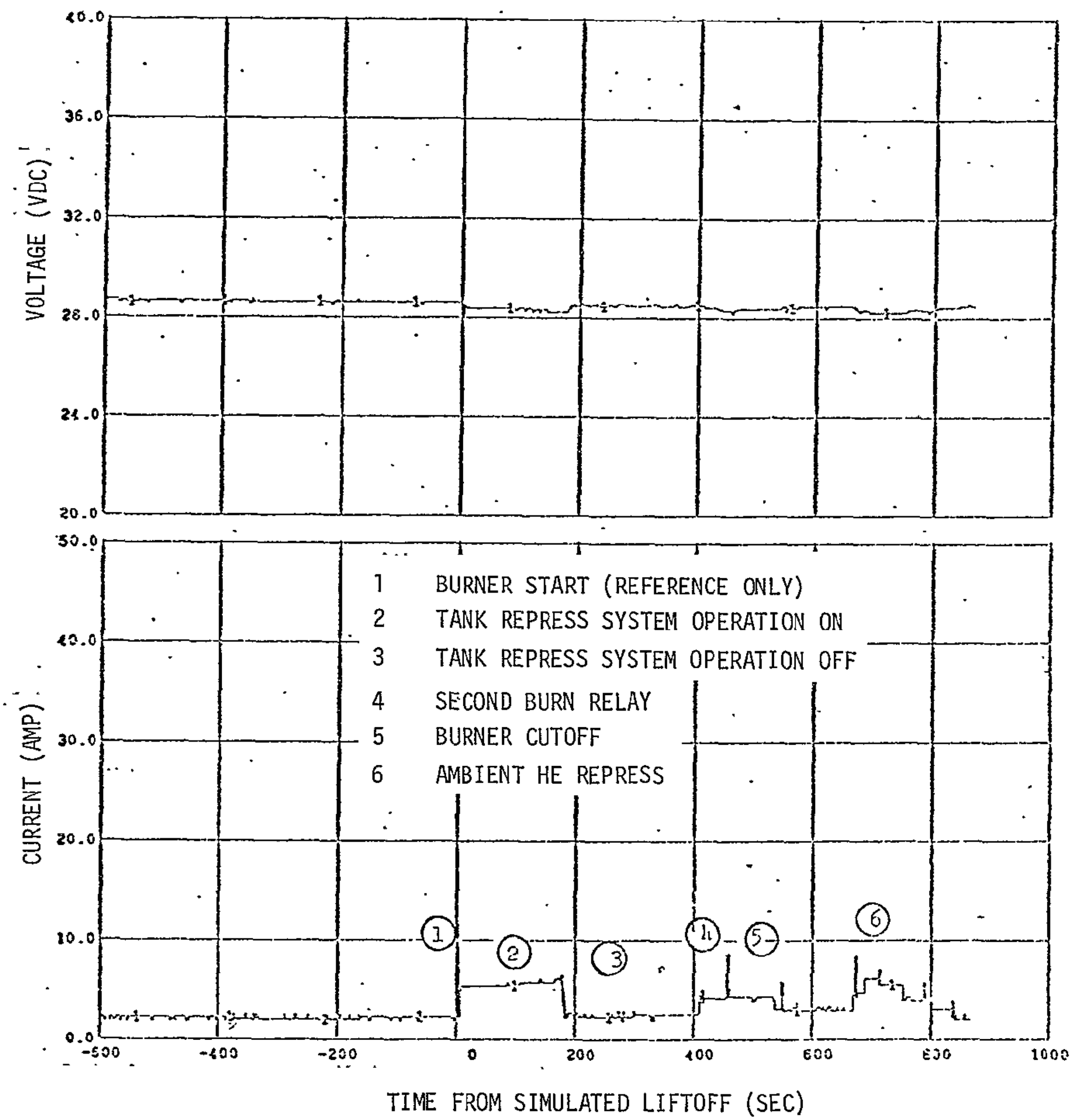

Figure 13-7. Aft Battery No. 1 Profile (O_2-H_2 Burner Firing)

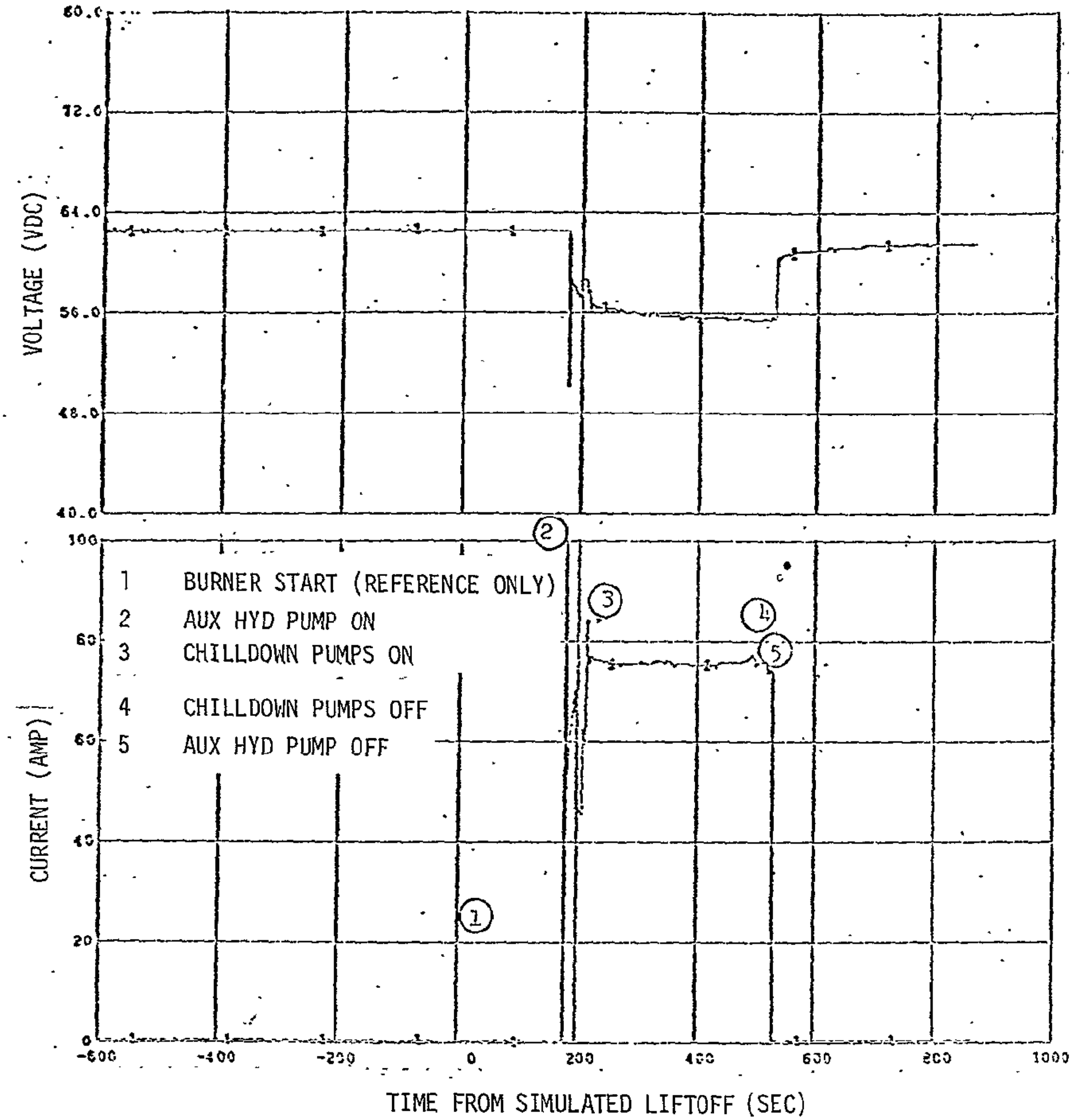

Figure 13-8. Aft Battery No. 2 Profile (O_2-H_2 Burner Firing)

SECTION 14

HYDRAULIC SYSTEM

14. HYDRAULIC SYSTEM

14.1 Hydraulic System Operation

The hydraulic system test program was conducted during countdown number 614116 during which the engine was successfully positioned and gimbaled. System running time for this test, from auxiliary pump ON prior to simulated liftoff to auxiliary pump OFF following cutoff, was 1,563 sec. The gimbal program was initiated after the engine start side loads subsided and the support links dropped. The auxiliary pump was turned off for 50 sec following the gimbaling program to verify satisfactory engine-driven pump operation.

Significant event times are presented in the following table:

Event	Approximate Time (sec)
Auxiliary Pump ON	T_0 -476
(Simulated Liftoff)	(T_0 +0)
Engine Ignition (engine-driven pump start)	T_0 +512
Support Links Dropped	T_0 +558
Gimbal Program Start	T_0 +581
Gimbal Program Stop	T_0 +637
Auxiliary Pump OFF	T_0 +657
Auxiliary Pump ON	T_0 +707
Engine Cutoff	T_0 +971
Auxiliary Pump OFF	T_0 +1,087

14.2 System Pressure at Salient Times

The GN_2 accumulator precharge pressure was 2,246 psia at 44 deg F just prior to starting the auxiliary hydraulic pump (T -500 sec). Correcting the gas pressure to 70 deg F temperature, the pressure value was within the 2,350 $\pm$50 psia allowable limits.

Test data indicated that the auxiliary pump discharge pressure increased to 3,650 psia in 19 sec after energizing the pump motor. Acceptable pump pressure was maintained from T_0 -476 sec through T_0 -0.

During the brief period of auxiliary pump cutoff (50 sec), the engine-driven pump pressure was 3,580 psia. This test indicated that the engine-driven pump was operating properly and within the required limits.

Aft battery No. 2 current (45 amp) shows that the auxiliary pump carried most of the hydraulic internal leakage load throughout the burn period, indicating the auxiliary hydraulic pump compensator was set above the engine-driven pump compensator.

One anomaly occurred during the static firing. The auxiliary hydraulic pump canister pressure regulator allowed the canister pressure to exceed the limits of 15 ±5 psig. Action is being taken to correct this anomaly.

The following is a tabulation of the remaining significant pressures:

Time (sec)	System Pressure (psia)	GN_2 Pressure (psia)	Reservoir Pressure (psia)
T_0 -457 (aux pump ON)	3,650	3,593	170
T_0 +0 (Simulated Liftoff)	3,650	3,615	178
T_0 +520 (After Ignition)	3,650	3,619	180
T_0 +581 to 636 (Gimbal)	3,650 max 3,580 min	3,619 max 3,541 min	180 max 177 min
T_0 +970 (Prior to aux pump OFF)	3,660	3,600	180

14.3 Reservoir Level at Salient Times

Reservoir level prior to system operation was 91 percent at an oil temperature of 45 deg F. The minimum level during operation was 34 percent which occurred 76 sec after auxiliary pump start.

14.4 Hydraulic Fluid Temperature History

Time (sec)	Engine-Driven Pump Inlet (deg F)	Reservoir (deg F)	Accumulator GN_2 (deg F)
T_0 -476 (aux pump ON)	50	45	44
T_0 +0 (Simulated Liftoff)	70	67	52
T_0 +520 (After Ignition)	88	77	52
T_0 +971 (Engine Cutoff)	100	86	52
T_0 +1,087 (aux pump OFF)	100	86	52

14.5 Engine Side Loads

Peak loads in the support links during engine start transients were as follows:

Item	Load (lbf)
Pitch Link	+20,000 - 14,000
Yaw Link	+12,000 - 21,000

14.6 Hydraulic Fluid Flowrates

Approximations from reservoir fill and emptying rates are presented in the following table:

Item	Flow (gpm)	Allowable (gpm)
System Internal Leakage	0.72	0.4 to 0.8
Auxiliary Pump Max Flowrate	1.68	1.50 min

14.7 Auxiliary Pump Motor Voltage and Current

Auxiliary pump motor electrical data were monitored only after the stage power source had switched to internal power (battery) and after the chilldown pumps had shutdown. The design requirements are as follows:

Voltage	51-61 vdc
Max Starting Current	300 amp
Max Operating Current	85 amp

The following table shows the values observed during the firing:

Time (sec)	Aft Bus No. 2 Voltage Supply (M540) (V)	Aft Battery No. 2 Current Load (M022) (amp)
T_0 +0	56	76
T_0 +530 (after ignition C/D pumps off)	56.5	48
T_0 +581 to +637 (Gimbal)	56.5 max 55 min	72 max 48 min
T_0 +707 (Turn aux pump on after brief shutdown)	46 min	190 peak
T_0 +950 (prior to engine C/O)	56.5	48

SECTION 15

FLIGHT CONTROL SYSTEM

15. FLIGHT CONTROL SYSTEM

The dynamic response of the hydraulic servo thrust vector control system was measured while the J-2 engine was gimbaling during the acceptance firing. The performence of the pitch and yaw hydraulic servo control system was acceptable.

15.1 Actuator Dynamics

The frequency response test of the pitch and yaw hydraulic servo control system for a ± 0.50 deg. sinusoidal signal between 0.6 and 9 cps, and for a ± 0.25 deg. sinusoidal signal between 0.6 and 2 cps verified the acceptability of the actuator responses. The acceptable limits and the gain and phase plots within these limits are presented in figures 15-1 and 15-2.

15.2 Engine Slew Rates

A nominal 2-deg step command was applied to the pitch and yaw actuators from which the engine slew rates were determined. The minimum acceptable engine slew rate is 8 deg/sec, which corresponds to an actuator piston travel rate of 1.66 ips. A nominal slew rate for a 2-deg step without the effects of gimbal friction is 13.6 deg/sec. The measured values were acceptable and are listed in the following table:

Actuator	Condition	Engine Travel (deg)	Engine Slew Rate (deg/sec)
Pitch	Retract	0.0 to + 2.0	11.4
	Extend	+2.0 to 0.0	11.8
	Extend	0.0 to - 2.0	12.5
	Retract	-2.0 to 0.0	11.4
Yaw	Extend	0.0 to + 2.0	11.8
	Retract	+2.0 to 0.0	11.4
	Retract	0.0 to - 2.0	11.6
	Extend	-2.0 to 0.0	11.9

The minimum engine slew rate obtained is 11.4 deg/sec. This corresponds to an actuator piston travel of 2.36 ips when using a conversion of 4.83 deg of engine movement per inch of actuator travel. Thus, in all cases, each actuator exceeded the minimum acceptable piston travel rate of 1.66 ips.

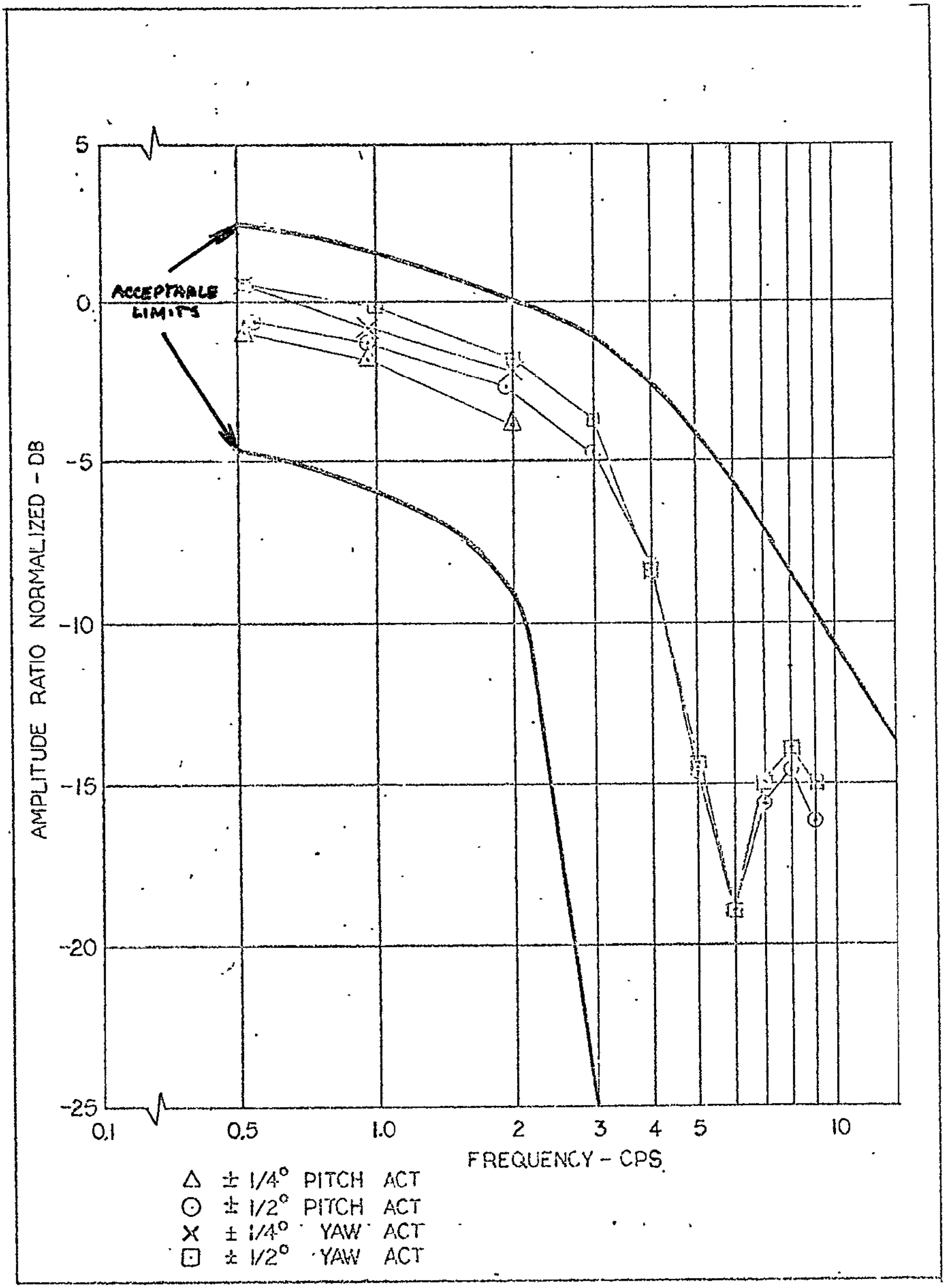

FIGURE 15-1 ACTUATOR RESPONSE - GAIN

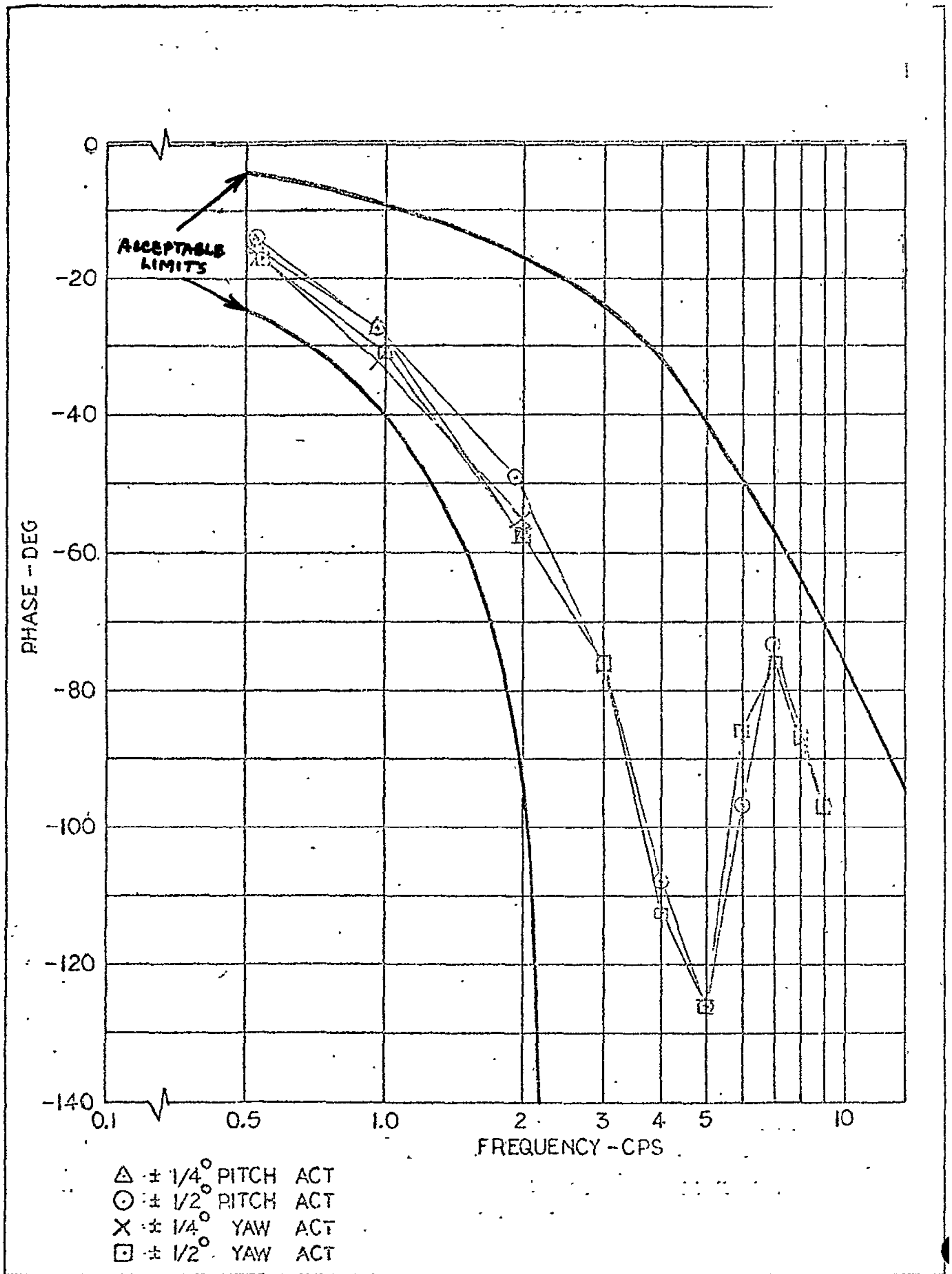

FIGURE 15-2 ACTUATOR RESPONSE - PHASE LAG

SECTION 16

STRUCTURAL SYSTEMS

16. STRUCTURAL SYSTEMS

Structural integrity of the S-IVB-508 Stage was maintained for the vibration, temperature, pressure, and thrust load conditions of the acceptance firing. With the exception of debonding and cracking of Korotherm ablative coating at two local areas on the forward skirt, no structural irregularities were encountered as a result of cryogenic loading, static firing, and O_2-H_2 burner firing. The damaged Korotherm coating is to be repaired under the direction of the Materials and Methods/Research and Engineering (MMRE) department. The Korotherm damage does not occur under CDDT or launch conditions at FTC due to the more effective thermal conditioning of the forward skirt at the launch facility.

16.1 Common Bulkhead

The results of the gas sample surveys, combined with satisfactory common bulkhead decay checks, indicate the bulkhead is sound and leak tight. During the actual acceptance firing, the bulkhead internal pressure readings were less than 1 psia. Gas sample analyses consistently indicated negligible quantities of hydrogen and helium gases within the common bulkhead. The pressure decay history and gas sample analyses recorded during prefire pumpdown, static firing, and post-firing activities are presented in Report DAC-61241, S-IVB-508 Stage Acceptance Firing 15-Day Report Sacramento Test Center, dated March, 1969.

16.2 Exterior Structure

A post-firing visual inspection of the S-IVB-508 stage exterior and accessible interior revealed no debonding of supports or brackets. The only evident structural degradation was debonding and cracking of Korotherm ablative coating around the forward skirt auxiliary tunnel area. The areas affected were 3 by 4 in. between stringers 13 and 14, a 4-in. hairline crack between stringers 14 and 15, and 2 by 3 in. on the flange between stringers 13 and 14. No cracking or peeling was noted in the main tunnel area.

16.3 LH2 Low Pressure Ducts

After acceptance firing, leak checks of the upper and lower duct vacuum jacket cavities indicated pressures close to ambient. Both were rejected. It was subsequently determined, however, that loss of vacuum in the upper jacket was not due to part failure. A loose vacuum valve or fitting was suspected as being the cause of loss of vacuum. Cracks were discovered in the middle bellows of the lower duct, and a Supplemental Failure Analysis is in progress on the lower duct.

16.4 Acoustic Environment

There were three flight acoustical measurements monitored on the aft skirt during the acceptance firing. One of the measurements was deleted during the firing because of a damaged transducer. The transducer will be replaced for flight. The acoustical levels shown in figure 16-1 were in agreement to those measured during past acceptance firings.

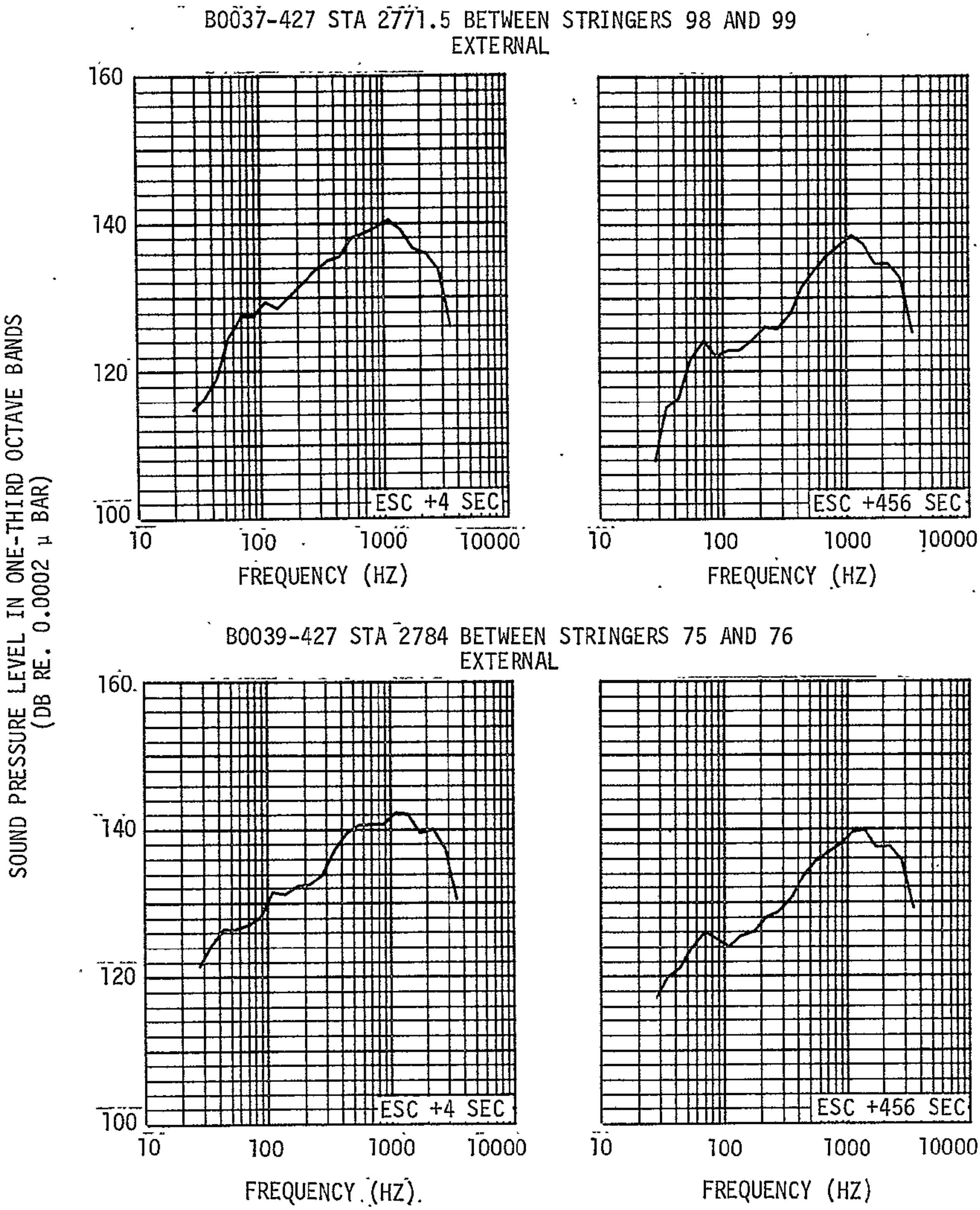

Figure 16-1. Acoustical Levels

SECTION 17

THERMOCONDITIONING AND PURGE SYSTEMS

17. THERMOCONDITIONING AND PURGE SYSTEMS

17.1 Aft Skirt Thermoconditioning and Purge System

The aft skirt environmental purge system thermally conditioned the aft skirt area with air and GN2. The air purge was initiated prior to LOX loading and was switched to GN2 prior to LH2 loading. Following LH2 loading, the air purge was reinitiated for test stand inspection, and then was switched back to GN2 for the rest of static firing. The purge flowrate was maintained essentially constant at the nominal 3,600 scfm, and the aft skirt environmental temperature (C0663) was approximately constant at 511 deg. R.

17.2 Forward Skirt Environmental Control and Thermoconditioning Systems

17.2.1 Forward Skirt Purge

The forward environmental purge system supplied the forward skirt with thermally conditioned GN2. The GN2 purge of the forward skirt was initiated prior to LOX loading and continued throughout the test until the completion of the tank purges. A flowrate of 500 scfm was maintained. The forward skirt GN2 supply temperature (C0768) was maintained between 499 and 503 deg. R.

17.2.2 Forward Skirt Thermoconditioning System

The forward skirt thermoconditioning system was supplied with coolant throughout the acceptance firing by the Model DSV-4B-359 Servicer. The coolant supply temperature (C0753) was maintained between 518 and 520 deg. R.

SECTION 18

EFFECTIVENESS ENGINEERING

18. Effectiveness Engineering

All functional failures of Flight Critical Items (FCI) and Ground Support Equipment/Special Attention Items were investigated by Effectiveness Engineering. Significant malfunctions of FCI's documented are noted in Table 18-1.

TABLE 18-1 (1 of 3)

FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE DESCRIPTION	CAUSE	ACTION TAKEN
1A66241-511 S/N X-458912	Pump, Hydraulic, Aux. Motor Driven	During the integrated system test per Procedure 1B55831, Rev. 31, the regulated outlet pressure of the gas pressure regulator was 33.976 psig instead of required 15 ± 5 psig.	To be determined.	Vendor replaced the gas pressure regulator on the stage without removing hydraulic pump.
1B40387-1 S/N 273	Module, Relay, 10 Ampere Magnetic latch	During P.U. Manual Calibration, forward Bus No. 2 was momentarily "shorted" to vehicle ground causing a current spike of 54 amps for 200 msec. Investigation of the circuit associated with the current spike revealed that the current exceeded the acceptable limits of the nickel ribbon conductor used within the relay module.	To be determined.	Component Standards Group requested the module to be removed from the vehicle and replaced. Part to be sent to A3-MRCC for further testing and investigation. Module not acceptable to engineering for use.

TABLE 18-1 (2 of 3)

FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE DESCRIPTION	CAUSE	ACTION TAKEN
1B42290-507-007C S/N 0037	Module, Control, LO_2 Tank Pressurization	During the critical components test of Stage Acceptance Firing, when the Cold He Shutoff Valves were opened, the regulator discharge pressure dropped to approximately 115 psia where it stayed. Normally, the pressure would drop to approximately 150 psia and immediately recover to 300 psia. The SCD allows 290 psia downstream pressure under high flow conditions.	The abnormal performance of the module was attributed to maximum stroking of the regulator pilot during the initial high demand coupled with an imbalanced flow condition between the regulator pilot and poppet metering pin as caused by temperature transient conditions within the module itself.	The module is to be removed from the stage and replaced. The -511 configuration is intended to alleviate the phenomenon when the module is operated within the extremes of the present operating conditions.
1B67598-501 S/N 202	Valve, Check, Pneumatic	During Propulsion System postfire leak checks per 1B71877, the LH_2 ambient repressurization primary inlet check valve was found to have a reverse leakage of 28 scim with a reverse pressure of 1450 psig He. The leak check procedure allows 10 scim.	To be determined. Note: Problems encountered in earlier failures have been associated with manufacturing process and have been corrected by vendor change effective S/N's 254 & subs.	Part removed from the stage, replaced and sent to A3-MRCC for review by engineering.

TABLE 18-1 (3 of 3)

FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE DESCRIPTION	CAUSE	ACTION TAKEN
1B69030-505 S/N 0024	Valve, Control, LOX, NPV	During the Acceptance Firing the valve cracked at 43.6 psia. The valve should not crack above 43.5 psia per 1B69030-J, Para. 4.3.3.2.2.5	The rejection request was generated from preliminary data only and based on one source readout only of 43.6 psia on the strip chart.	The valve was found acceptable for use. Further data investigation revealed that the analog data from three different sources indicates a satisfactory cracking pressure as follows: D0540 - 43.1 psia, D0179 - 42.6 psia, and D0180 - 43.5 psia.

APPENDIX I

ABBREVIATIONS

TABLE AP 1-1 (Sheet 1 of 3)
ABBREVIATIONS

Item	Term
ac	Alternating current
Act	Actuator
APS	Auxiliary Propulsion System
ASI	Augmented Spark Igniter
attch	Attach
A_t	Throat area
Aux	Auxiliary
Btu	British thermal unit
Bgr	Bridge gain ratio
c_f	Thrust Coefficient
CDDT	Countdown Demonstration Test
Cfm	Cubic feet per minute
Contr	Control
cpg	Cycles per gallon
cps	Cycles per second
db	Decibel
dc	Direct current
DDAS	Digital Data Acquisition System
deg	Degree
DER	Digital Events Recorder
Disch	Discharge
DNA	Data not available
D/O	Dropout
DPF	Differential Pressure Feedback
EBW	Exploding bridgewire
ECC	Engine Cutoff Command
ECO	Engine Cutoff
EDS	Emergency Detection System
E/I	External/Internal
EMI	Electromagnetic Interference
EMR	Engine Mixture Ratio
ESC	Engine Start Command
F	Fahrenheit
F	Thrust
FCI	Flight Critical Items
Flt	Flight
ft	Feet
FM	Frequency modulation
FTC	Florida Test Center
Fwd	Forward
GG	Gas generator
GH2	Gaseous hydrogen
GIS	Ground Instrumentation System
GN2	Gaseous nitrogen
gpm	Gallons per minute
GSE	Ground support equipment
HB	Huntington Beach
He	Helium
Hg	Mercury
H_2O	Water
hr	Hour
hp	Horsepower
Hyd	Hydraulic
Hz	Hertz
in.	Inch
ips	Inches per second
IP&CL	Instrumentation Program and Components List
I_{sp}	Specific impulse

TABLE AP 1-1 (Sheet 2 of 3)
ABBREVIATIONS

Item	Term
IU	Instrument Unit
K	Kilo - 1,000 or 10^3
Kc	Kilocycle
KSC	Kennedy Space Center
lbf	Pounds force
lbm	Pounds mass
LH2	Liquid hydrogen
Loc	Location
LOX	Liquid oxygen
M&A	Manufacturing and Assembly
MDAC-WD	McDonnell Douglas Astronautics Company - Western Division
MR	Mixture ratio
ms	Millisecond
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
N/A	Not applicable
NPSP	Net positive suction pressure
P_c	Chamber pressure
PCM	Pulse code modulation
PDT	Pacific Daylight Time
pf	Picofarad
Posit	Position
pps	Pulses per second
Press	Pressure
psi	Pounds per square inch
psia	Pounds per square inch, absolute
psid	Pounds per square inch, differential
psig	Pounds per square inch, gauge
PST	Pacific Standard Time
Pt	Point
P/U	Pickup
PU	Propellant Utilization
Pwr	Power
R	Rankine
RACS	Remote Analog Checkout System
RAD	Radial
Refl	Reflected
Reg	Regulator
RF	Radio Frequency
RMR	Reference Mixture Ratio
rpm	Revolutions per minute
RSS	Root sum square
SAI	Special Attention Items
scc	Standard cubic centimeter
sci	Standard cubic inch
scim	Standard cubic inch per minute
scfm	Standard cubic foot per minute
sec	Second
sps	Samples per second
SSB	Single sideband
STC	Sacramento Test Center
sw	Switch
Syst	System
T_0	Simulated liftoff
TAN	Tangential

TABLE AP 1-1 (Sheet 3 of 3)
ABBREVIATIONS

Item	Term	Item	Term
Temp	Temperature		
T/M	Telemetry		
TP&E	Test Planning and Evaluation		
vac	Volts alternating current (100 vac)		
V	Volts		
VCL	Vehicle Checkout Laboratory		
vdc	Volts direct current		
Vib	Vibration		
vswr	Voltage standing wave ratio		
$\dot{W}_T$	Total mass flowrate		

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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